Planting date, row spacing, and seeding rate effects on soybean yield and yield components

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INTRODUCTION

Soybean [*Glycine max* (L.) Merr.] is a major commodity in the United States (U.S.) and all over the world. In the early 1920s, soybean was mainly an ornamental crop or a forage crop in the U.S., with only about 179,000 hectares grown annually. Today U.S. producers devote over 28,000,000 hectares to soybeans each year (USDA/NASS, 1999). Over time, soybean yields have steadily increased along with the increase in total hectares being produced. In the 1920s, soybean seed yields averaged approximately 700 kg/ha; in 1998 U.S. soybean producers harvested approximately three and a half times that amount, averaging 2,400 kg/ha (USDA/NASS, 1999).

In 1998, U.S. producers accounted for 49 percent (%) of world soybean production (USDA/NASS, 1999). U.S. soybean production is heavily concentrated in the Upper Midwest region. In 1998, the top ten soybean producing states (Iowa, Illinois, Minnesota, Indiana, Missouri, Ohio, Nebraska, South Dakota, Kansas, and Michigan, respectively) accounted for 84% of the U.S. soybean crop (USDA/NASS, 1999). Iowa farmers produced 18% of the total U.S. soybean crop in 1998. Iowa and Illinois typically lead the U.S. in total hectares of soybeans harvested and in total per-hectare yield. In 1998, Illinois harvested more hectares of soybeans but achieved yields 8% less than Iowa (USDA/NASS, 1999). When figured into the total world production, Iowa alone produces 9%. If Iowa and Illinois are coupled together in this figure we see that approximately 18% of the total world soybean supply comes from these two states. This figure is only 2% less than Brazil, which ranked second worldwide in soybean production in 1998 with 20% (USDA/NASS, 1999). These figures demonstrate the relative importance of soybean production in the U.S. Midwest.

Soybeans initially gained popularity with U.S. producers mainly for their benefits in crop rotations. Producers experimenting with soybeans saw direct and positive results when using it in their rotation sequence. Due to its rotation advantages with corn and an increase in marketability, the soybean soon became the second largest U.S. agricultural commodity based on dollar amount (USDA/NASS, 1999). This quick growth in popularity resulted in producer questions about management of soybeans.

Throughout the first few decades of U.S. soybean production many producers used cultural practices also used in corn production, planting and cultivating their soybeans with the same equipment used in corn production. Soybeans were typically planted in row widths ranging between 76- and 102-cm. Producers depended upon mechanical cultivation for weed control. Horses were used in the 1920s to do this cultivation; therefore, row widths needed to be wide enough to allow the horses to pass between them. Advances in technology such as the use of tractors, row crop cultivators, herbicides, and the development of better soybean breeding programs have led to many changes in soybean management programs.

This new equipment led to a decrease in the most common row widths from 102 cm to 96.5 and 91 cm. The development of new herbicides and new soybean varieties by the vastly increasing number of seed and chemical companies made these changes in management more common.

The development of new and improved equipment, such as the grain drill, started to introduce producers to narrow-row soybeans. The drill was used primarily as a planting tool for forages, oats, and wheat. It soon became common for producers to use it in soybean production as well. The drill enables producers to plant soybeans in row widths ranging between 17- and 51-cm.

Today, chemical companies continue to make advances in their lines of products, developing many new herbicides each year. The successes of many of these herbicides have continued to give producers the opportunity to use them in place of mechanical cultivation as a primary weed control practice. The popularity of no-till and minimum tillage practices have also helped to make narrow-row soybean production more accepted.

Previous soybean management research in the upper Midwest has shown a yield advantage for narrow row widths over soybeans produced in wider rows (Caviness and Smith, 1959; Timmons et al., 1967; Cooper, 1977; Beatty et al., 1982; Oriade et al., 1997). This yield advantage can be attributed to the increase in light interception (Shibles and Weber, 1966; Weber et al., 1966; Taylor et al., 1982; Board et al., 1992). Improved planting equipment and increased weed control options have made it easier to produce narrow-row soybeans today; however, producers continue to question which row spacing is best for their modern soybean management plan. What is the best plant population to use with narrow row spacing? Does planting date influence soybean yield response to different row spacings, plant populations, or combinations of the two? These are two commonly asked questions in soybean management today. Advances in agricultural technology have kept the answers to these questions inconsistent and continually changing.

The goal of this research is to help answer some of these soybean management questions. This research was conducted with the modern equipment and soybean varieties available to producers today. This experiment evaluates twenty-seven different management treatments. Three common row widths, three plant populations, and three different planting dates are used as the variables in this research. The results are hoped to help answer many of the producers' questions about which soybean management techniques are best for their operations.

Thesis Organization

This thesis is organized in the following manner. It begins with a literature review. This is followed by the methods and materials used in each year and location. The results and discussion are presented next, followed by the conclusions. The thesis then concludes with the literature cited and acknowledgements.

LITERATURE REVIEW

Planting Date Effects on Soybean Yield

Planting date studies conducted in the past have produced consistent results. Soybean yields tend to be reduced when they are planted later in the season (Caviness and Smith, 1959; Cartter and Hartwig, 1963; Smith, 1968; Carter, 1974; Graves et al., 1978). Studies also have indicated that the optimum planting date primarily differs among cultivars of different maturity groups (Egli, 1975; Johnson and Major, 1979; Anderson and Vasilas, 1985). A delay in planting date will shorten the vegetative growth phase of later maturing cultivars, and shorten the reproductive growth phase in earlier maturing cultivars (Abel, 1961). These effects arise because of the photosensitive nature of soybeans and the differences in critical daylength necessary to trigger bloom in different maturing cultivars (Anderson and Vasilas, 1985).

When planting date, row spacing, and cultivar variables are evaluated together, planting date has the greatest single influence on yield (Ryder and Beuerlein, 1979; Beaver and Johnson, 1981). Many studies also have indicated an interaction between planting date and row spacing. Some studies have indicated that later planted soybeans will respond better to narrow rows than to wide rows (Cooper, 1971b; Costa et al., 1980).

In Illinois, Beaver and Johnson (1981) found that yields declined an average of 33% as planting was delayed from early May to early July. Over three years, indeterminate cultivars produced top yields on the earliest planting date (an average planting date of 13 May). In each year, the yields of the indeterminate cultivars declined linearly after the first planting date. Also in Illinois, Anderson and Vasilas (1985) reported a significant yield reduction for two indeterminate cultivars when planting was delayed from mid-May to mid-June. They concluded that soybean yield reductions associated with planting delays reduced seed number and seed size. Both of these yield components were severely hindered by dry growing conditions and late planting dates. The decrease in total seed number was mostly attributed to the negative effect of delayed planting (mid-June) on vegetative growth during the R1-R5 (Ritchie et al., 1994) stages of development.

In Ohio, Beuerlein (1988) studied the effects of planting date along with row spacing and seeding rates. He also found that delayed planting reduced yields significantly. Planting dates used in his study were 1 May, 20 May, and 10 June. Averaged over all row spacings and seeding rates, the planting date yields were 3621, 3313, and 2723 kilograms/hectare (kg/ha) respectively. The late planting date resulted in a yield decrease of approximately 25% versus the early date. Some individual treatments in the study resulted in more than a 30% yield reduction when planting was delayed from 1 May to 10 June.

In Minnesota, Lueschen et al. (1992) found that early planting dates resulted in higher soybean yields in 12 of 15 environments and reduced yields in only one environment. An extremely wet spring in 1984 delayed "early" planting leaving only 11 days between planting dates and producing the three environments without a positive yield response to early planting.

In Wisconsin, Oplinger and Philbrook (1992) studied the effect of planting dates along with row spacing and tillage. They found that soybeans planted 15 May and 31 May had no significant yield difference averaged over two row spacings and three tillage treatments; however, soybeans planted on 13 June yielded significantly less (17%) than those planted on the first two dates. Soybeans planted in mid-June did respond to tillage treatments; "complete tillage" produced yields 11% higher than the "reduced" and "no-till" treatments. Also in Wisconsin, Grau et al. (1994) found that averaged over two years yield of soybeans planted 1 May was 6% greater than those planted 15 May and 22% greater than those planted on 30 May. Grau et al. (1994) reported that seed weight was not significantly affected by planting date, indicating that the primary reason for yield loss with delayed planting was reduced number of seeds.

In Iowa, Lundvall and Whigham (1999) found that modern, high-yield cultivars generally responded favorably to early planting. They used six planting dates ranging from 28 April to 11 July and found that when averaged over three years, yield decreased linearly as planting date was delayed. In central Iowa, soybeans planted April 28 produced yields 63% higher than those planted on 11 July. They found similar planting date responses at the northern and southern Iowa research locations (cultivars differed with geographic location). These results suggest that new soybean cultivars are better able to tolerate the growing conditions that are encountered in April than many of the previous cultivars used (Whigham, 1998). Planting delays to mid-May did not significantly reduce the yields; however further planting delays did produce consistent significant reductions in yield. In short, early planting should improve soybean yield potential. An early planting date results in a higher or statistically similar yield and greatly decreases the risks of severe yield loss due to later season planting delays from unfavorable weather conditions.

Row Spacing Effects on Soybean Yield

Soybean row spacing comparisons have been conducted for many years and continue to be studied with the advancements in equipment and soybean varieties. Past research has shown a fairly consistent yield increase as soybean row width is narrowed (Caviness and Smith, 1959; Timmons et al., 1967; Cooper, 1977; Costa et al., 1980; Beatty et al., 1982). Hackleman et al. (1916) was one of the first researchers to report that soybeans grown in 51-cm row widths yielded better than those grown in 102-cm rows. Wiggans (1939) reported a further soybean yield increase as row width was narrowed to 21-cm. In 1940, Burlison et al. reported an optimum row width of 24-cm.

Row spacing studies conducted throughout the U.S. Midwest have produced consistent results. In Iowa, Benson and Shroyer (1978) summarized results of research conducted from 1960-1977 on the influence of row spacing on soybean yield. They found that if moisture stress is limited and all production inputs are provided, a producer could expect a 17 to 22% yield increase as soybean row width narrows from 102-cm rows to 25-cm. Also in Iowa, Taylor (1980) reported that over three years when water supply was “high” or “adequate”, soybeans planted in 25-cm rows yielded 17% better than those planted in 100-cm rows. Taylor also concluded that in years of lower seasonal water supplies, there was no significant yield difference among the 25-, 50-, 75-, and 100-cm row spacings. This research supported the hypothesis that there is a row spacing by water supply interaction. Bharati (1984) reported on row spacing and population effects on soybean seed yield in Iowa; averaged over three population levels, soybeans planted in 25- and 51-cm row widths yielded significantly better than those planted in 76-cm rows. His results did not show a statistical difference in yield for 25- and 51-cm rows.

A more recent Iowa study conducted by Wykle (1997) compared 76-, 38-, and 19-cm row spacings. Averaged over two years, two plant populations, four cultivars, and three planting methods, row spacing had no statistically significant effect on soybean yield; however, yields did trend higher as row spacing was narrowed. Further, the yield trend was greater in a growing season of unfavorable conditions. Lundvall and Whigham (1999) reported on three years (1997-1999) of soybean row spacing comparisons across Iowa. In five of six locations, soybean yield was higher or statistically similar for 38-cm rows when compared to 76-cm rows. In a growing season (1999) with limited rainfall during the seed production stages, all six locations produced the highest yields in 38-cm rows.

In Illinois, Reiss and Sherwood (1965) compared five different row spacings (20-, 41-, 61-, 81-, and 102-cm). Highest yields were obtained from the 61-cm rows followed by the 41-, 20-, 81-, and 102-cm rows, respectively. The yields were consistent over all plant populations and fertility levels used. Hicks et al. (1969) studied the combination of row width, population, and cultivar. They found no significant yield differences in one year between 76- and 25-cm rows but found that the 25-cm rows increased yield by 6.5% in the second year.

In other Illinois studies, Cooper (1971b) reported on row spacing and found that 17-cm rows provided yield advantages over 50- and 75-cm rows. More uniform plant distribution in the 17-cm row spacing resulted in more equally competitive plants, which increased the number of surviving plants that produced seed in 17-cm rows. Cooper supported his own results again in 1977 when he found that 17-cm rows had a yield advantage of 10 to 20% over 50- and 75-cm rows (Cooper, 1977). His data in 1977 also showed that the row spacing effect is greater with early maturing cultivars. He found yield increases ranging between 30 and 40% for 25-cm rows with the earliest maturing cultivars. In 1981, Beaver and Johnson found that soybean yields increased between 5 and 9% when row spacing was decreased from 80- to 50-cm. They found no yield differences between 50- and 20-cm rows.

In Wisconsin, Costa et al. (1980) published results supporting the use of narrow rows. Over three years, multiple plant populations, and multiple cultivars, soybeans grown in 27-cm rows yielded 21% better than those planted in 76-cm rows. Earlier maturing cultivars tend to have a greater yield response to narrow rows, supporting earlier work of Wiggans, 1939; Lehman and Lambert, 1960; and Cooper, 1977. In 1992, Oplinger and Philbrook studied the effects of planting date, row spacing, and seeding rate in three different tillage treatments in Wisconsin. When averaged over all populations, tillage methods, and planting dates, they observed a yield increase of approximately 7% for soybeans planted in 20-cm rows over those planted in 76-cm rows. A 1994 Wisconsin study conducted by Grau et al. supported the findings of Oplinger and Philbrook. The study was conducted to see if planting date and row spacing had any effect on the severity of brown stem rot (BSR). They found no interaction between BSR and row spacing, but did see an overall soybean yield increase of 15% for 18-cm rows over 76-cm rows when averaged over years, cultivars, and planting date.

In Minnesota, Hugie and Orf (1989) found 25-cm rows consistently produced higher yields than 76-cm rows in four different environments, regardless of cultivar. In another Minnesota study, Lueschen et al. (1992) found an average yield increase for 25-cm rows of 8 to 14% over 76-cm rows when averaged over tillage method and planting date.

In Ohio, Beuerlein (1988) compared row spacings of 18-, 25-, 36-, and 51-cm in two different indeterminate cultivars. There was no significant yield difference between the 18- and 25-cm spacing for either cultivar. These two row widths did, however, produce a significantly higher yield than the 36- and 51-cm rows. The latter two row spacings produced similar yields in both cultivars as well. Walker and Fioritto (1984) found that decreasing row width from 76- to 19-cm resulted in a yield increase of 18%. Cooper and Jeffers (1984) found that decreasing row width from 75- to 17-cm increased soybean yield in Ohio 15 to 25%. Cooper and Jeffers reported that the narrow-row yield increase was minimized or eliminated if the soybeans were placed into nitrogen-stressed situations. In 1991, Hesterman and Isleib supported this finding with a study conducted in Michigan. They found that when studying effects of row spacing, inoculation treatment, and nitrogen fertilizer on first year soybean yield, nitrogen was a limiting factor. In Saginaw, on soils high in nitrogen, soybeans yielded 3601, 4271, and 5163 kg/ha for 76-, 51-, and 25-cm rows, respectively. In Huron, where soils were low in nitrogen, there was no yield response to row spacing.

Delvin et al. (1995) conducted a study in Kansas and reported a row spacing by plant population interaction. They found that increased seeding rates affected soybean yields differently in 20- and 76-cm rows. Maximum yield for the 76-cm rows was 3822 kg/ha at a seeding rate of 247,170 seeds per hectare. Maximum yield for the 20-cm rows was 3956 kg/ha at a seeding rate of 501,410 seeds per hectare. Seeding rates up to 377,910 seeds per hectare produced top yields in 76-cm rows, whereas seeding rates greater than 377,910 seeds per hectare produced higher yields in 20-cm row widths.

In 1991, Albett et al. conducted a study in southern Canada to evaluate row spacing and seeding rate effects on yield of determinate, indeterminate, and semi-determinate cultivars. Three row spacings (25-, 51-, and 76-cm) were compared. All three growth types increased yields as row width decreased. The indeterminate cultivars gained 14%, the semi-determinate cultivars gained 20%, and the determinate cultivars gained 23% in yield when decreasing the row width from 76- to 25-cm. The recent development of some Group I and Group II determinate and semi-determinate cultivars increase the importance of this research for producers in the northern parts of the U.S. Midwest. Producers that are experiencing lodging problems in high-yielding areas can use these adapted determinate and semi-determinate cultivars to help avoid excessive harvest losses due to lodging. The results found by Albett et al. (1991) show that using narrow (25-cm) row widths can maximize the use of these adapted cultivars. In 1998, Elmore planted indeterminate, semi-determinate, and determinate cultivars in 25-, 51-, and 76-cm rows in southcentral Nebraska, using both rainfed and irrigated environments. Elmore's results differed from those of Albett et al. Over all seeding rates, soybeans planted in 51-cm rows produced the greatest yields. The primary reason for the lower yield in 25-cm rows was attributed to the problems initiated by excess moisture. The irrigated soybeans grown in 25-cm rows had a much higher disease (*Sclerotina Sclertiorum*) occurrence due to the moisture.

The increase in yield for narrow rows can be attributed to the increase in light interception (Shibles and Weber, 1966). Soybean yield can not be maximized unless 95% light interception and full canopy is achieved before seed and pod development begins (Shibles and Weber, 1966). More recent studies (Board et al., 1992) have indicated that full canopy must be achieved by beginning flower (R1) (Ritchie et al., 1992) to reach maximum yield. Decreasing row spacing shortens the amount of time between plant emergence and full canopy (Hicks et al. 1969). The narrow rows help the plant achieve higher interception of solar radiation and increase photosynthesis earlier in the growing season, leading to higher seed yields (Shaw and Weber, 1967).

In addition to light interception advantages, many researchers have found that narrow row soybeans also have a higher water use efficiency (Peters and Johnson, 1960; Timmons et al., 1967; Taylor, 1980). In Iowa, Taylor (1980) found that in a season of above normal precipitation, soybeans grown in 25-cm rows had higher water use efficiency than those grown in 100-cm rows. Late-season soil water content indicated that 102-cm rows did not efficiently use all of the water available, whereas the 25-cm rows did. Taylor found that in years of adequate or above normal precipitation, 25-cm rows produced 17% higher yields than 102-cm rows. He also found that in water-limited seasons there was no advantage, and in some cases a slight disadvantage, to narrow rows. These data have been supported by several other researchers (Timmons et al., 1967; Stone et al., 1976; Alessi and Power, 1982).

Planting soybeans in narrow rows can also help control weeds. Several studies have demonstrated that soybeans planted in rows widths narrower than 25-cm shade and suppress weeds better than the wider rows due to a faster canopy closure (Burnside and Colville, 1964; Wax and Pendleton, 1968; Légère and Shreiber, 1989). In Michigan, Mickelson and Renner (1997) found that weed control and soybean seed yield was greater in 25-cm rows than in 76-cm rows; further, herbicide application rates could be reduced up to 50% without reducing yield of soybeans grown in 25-cm rows. This result was not observed with soybeans grown in 76-cm rows.

Reduced soil erosion potential is another advantage associated with narrow-row soybean production. Reduced erosion was one of the first reasons for planting soybeans in narrow rows. In 1936, Miller compared soybeans grown in 107-cm rows to soybeans seeded with a grain drill in 25-cm rows. Soil erosion was reduced by more than 50% by narrowing row width from 107-cm to 25-cm. In Indiana, Mannering and Johnson (1969) evaluated effects of crop row spacing (18-, 51-, and 102-cm) on erosion. Soil loss was reduced by 70% with the 18- and 51-cm rows. Colvin and Laflen (1981) reported that Iowa producers could reduce annual soil erosion losses by 2273 kg/ha by switching from 76- to 25-cm rows.

Seeding Rate and Plant Population Effects on Soybean Yield

Soybean yield response to seeding rate has been inconsistent in past research (Lehman and Lambert, 1960; Timmons et al., 1967; Basnet et al., 1974; Albett et al., 1991). Many studies have demonstrated the soybean plant's ability to compensate for reduced stand levels, showing no yield differences over a wide range of plant populations (Wiggans, 1939; Wilcox, 1974; Alessi and Powers, 1982; Beuerlein, 1987; Carpenter and Board, 1997; Whigham and Lundvall, 1998). Wilcox (1974) tested a wide range of plant populations ranging from 25,000 to 582,000 seeds per hectare. His results showed that plant density can vary up to 27% of the optimum level in a single cultivar and yields will remain statistically similar. Costa et al. (1980) found that varying harvest plant populations in 27-cm rows from 247,000 plants per hectare to 741,000 plants per hectare produced no significant yield response. He found the same results with plant populations ranging from 132,000 to 526,000 plants per hectare in 76-cm row widths. In Illinois, Beaver and Johnson (1981) used seeding rates ranging from 350,000 to 650,000 seeds per hectare, and they found no significant yield response to seeding rate with determinate or indeterminate cultivars. A three-year, three-seeding rate (171,000, 342,000, and 513,000 per hectare) comparison by Lueschen and Hicks (1977) in Minnesota found no significant yield response to higher seeding rates in two of three years. Increased seeding rate did result in higher yields in 1974, a growing season with mid-June hail damage and an early killing frost (3 September). Other researchers have demonstrated a yield response to increased populations only under plant-stressed growing conditions. Alessi and Power (1982) found no differences in yield when plant populations ranged from 48,000 to 580,000 plants per hectare; however, reduced yields under drought stress were associated with higher seeding rates and resulting increased plant populations.

Other studies have demonstrated that increased plant populations can increase soybean yield (Reiss and Sherwood, 1965; Albett et al., 1984; Duncan, 1986; Oplinger and Philbrook, 1992; Delvin et al., 1995). In Wisconsin, Oplinger and Philbrook (1992) studied the effect of seeding rate and row spacing among three different tillage methods. They used six seeding rates ranging from 123,500 to 741,000 seeds per hectare. Averaged over all tillage methods and row widths, top soybean yields were achieved at the high end (494,000 to 741,000 seeds per hectare) of the three seeding levels. These three rates produced similar yields that were significantly higher than the yield of the lower three seeding levels. The researchers also were able to conclude from this study that the optimum seeding rate varies with tillage method. Maximum yields were achieved with the "conventional tillage" method at a seeding rate of 434,720 seeds per hectare. Optimum seeding rates for the "no-till" and "reduced-till" methods were higher, 573,040 seeds per hectare. These findings supported past research showing that optimum seeding rates need to be increased between 15 and 32 percent when planting into no-till or reduced-till seed beds (Cooper, 1977; Beuerlein, 1980; Beuerlein, 1987).

Some research has shown that increased plant populations may reduce yields (Williamson, 1974; Albett et al. 1991). Albett found that yield of determinate cultivars was reduced significantly when seeded at a rate of 790,400 seeds per hectare, versus 395,200 seeds per hectare. Hoggard et al. (1978) compared seeding rates ranging from 240,000 to 540,000 seeds per hectare. Highest yields were obtained at the lowest plant populations in all treatments. Soybean yields tend to decrease with increased plant population in extremely dry seasons (Williamson, 1974; Alessi and Power, 1982).

Some research has shown that plant population responses can vary according to row width being used (Timmons et al., 1967; Basnet et al., 1974; Boquet, 1990; Delvin et al., 1995). In a Minnesota study conducted by Timmons et al. (1967), soybeans planted in 20-cm row widths obtained their maximum yields at the lowest plant populations (226,378 seeds/ha). Soybeans grown in 102-cm rows required higher seeding rates to reach maximum yields. Yield response differences were attributed to the narrow rows having increased water use efficiency. In Illinois, Cooper (1971b) found that soybeans grown in 17-cm row widths reached maximum yields at lower populations than in 50-cm rows due to a higher percentage of plant survival and less lodging in 17-cm rows. These results contradict previous work suggesting narrow rows require a higher seeding rate than wide rows to produce maximum yields (Reiss and Sherwood, 1965; Weber et al., 1966). In Kansas, Delvin et al. (1995) studied effects of five soybean seeding rates ranging from 129,111 to 645,559 seeds per hectare and two row widths (20- and 76-cm) on yield. They found that the optimal seeding rate under high yielding conditions varied according to the row width being used, supporting the findings of Reiss and Sherwood (1965) and Weber et al. (1966). Soybeans planted in 76-cm rows produced maximum yields when seeded at 284,050 seeds per hectare, whereas 20-cm rows did not reach their maximum yields until the seeding rate reached 501,410 seeds per hectare.

There have been inconsistent reports on soybean response to seeding rate being influenced by cultivar (Probst, 1945; Hinson and Hanson, 1962; Costa et al., 1980; Bowen and Schapaugh, 1989). Many studies have indicated a more significant yield response between soybean growth types than between cultivars (Beuerlein, 1988; Albett et al., 1991; Elmore, 1998). In 1988, Beuerlein found that increasing the plant population of an indeterminate cultivar did not affect the yield; however, an adapted determinate cultivar with a similar maturity to the indeterminate cultivar exhibited a significant yield increase when population was increased from 370,500 to 494,000 seeds per hectare. In 1991, Albett et al. evaluated row spacing and seeding rate effects on yield of determinate, indeterminate, and semi-determinate soybean growth types. The study included three seeding rates of 395,000, 592,800, and 790,400 seeds per hectare. They found very little response to the population variable. The indeterminate and semi-determinate cultivars showed no yield response to seeding rate under non-stressed growing conditions; however, determinate varieties yielded significantly more when seeded at a rate of 592,800 seeds per hectare than at other rates. Elmore (1998) also observed this response in Nebraska. Elmore's study was very similar to that of Albett et al. (1991), except it was conducted in an irrigated environment. Elmore used plant populations of 111,150, 345,800, 568,100, and 815,100 seeds per hectare. He found no statistically significant responses to plant population with the indeterminate and semi-determinate cultivars; however, determinate cultivars planted at 345,800 seeds per hectare yielded 42% more than the same cultivars planted at 111,500 seeds per hectare. Yield was unchanged as population increased beyond 345,800 seeds per hectare.

Effects of Planting Date, Seeding Rate, and Row Spacing on Soybean Plant Height and Yield Components

Soybean plant height is affected by planting date. Many studies have indicated that a delay in planting will reduce plant height (Beaver and Johnson, 1981; Beatty et al., 1982; Anderson and Vasilas, 1985). Early planting date can reduce plant height as well. Whigham and Lundvall (1998) found that soybeans planted in late April were shorter than those planted in early to mid-May. This reduction in height can be attributed to stress caused by the cool and wet growing conditions that were experienced during early vegetative growth stages.

Reports of row spacing effect on soybean plant height are inconsistent. In many studies, plant height increased as row spacing decreased (Hicks et al., 1969; Beaver and Johnson, 1981; Bharati, 1984). Other studies have indicated that plant height is reduced with a decrease in row spacing (Sesay, 1972; Taylor 1980). Weber et al. (1966) found plant height to be unaffected by row spacing. In 1997, Wykle found no significant plant height differences for 19-, 38-, and 76-cm rows. Other research has indicated that the row spacing by plant height interaction is dependent on water availability. If moisture is limited, there will be no plant height response to row spacing (Pendleton et al., 1960; Elson, 1986).

Soybean plant populations also consistently influence plant height. Many studies have indicated that plant height will increase with an increase in plant population (Johnson and Harris, 1967; Wilcox, 1974; Beaver and Johnson, 1981; Wykle, 1997; Tranel, 1999). Similar to the interaction found between plant height and row spacing, plant population and row spacing interaction is dependent on adequate soil moisture. Delvin et al. (1995) found that in years of moisture stress, plant height remained constant over a wide range of seeding rates.

Soybean yield is made up of three components: total number of pods per plant, seeds per pod, and seed weight. These components can be affected by soybean producers' management techniques. Certain management strategies will affect these components more severely than others. To assure maximum seed yield, producers should avoid management techniques that hinder any of these yield components. Past studies have revealed some management techniques that have hindered these components and reduced yields.

Several studies have found that delayed planting dates have a negative effect on yield components. Beatty et al. (1982) found that a delay in planting date reduced the number of pods per plant and reduced seed weight. Anderson and Vasilas (1985) also found that planting delays decreased seed size. In their research they found a strong cultivar by planting date interaction. One cultivar responded to planting delays by producing fewer pods per plant, while another cultivar produced fewer seeds per pod and lower seed weights. More recently, Grau et al. (1994) found that seed weight was not affected by delays in planting.

The effect of row spacing on soybean yield components also has been evaluated, with inconsistent results. In 1965, Reiss and Sherwood found that decreasing row width decreased seed weight. Other research, however, has found that row spacing has no influence on seed weight (Basnet et al., 1974; Hugie and Orf, 1989; Grau et al., 1994). Many studies have concluded that number of pods per plant increased as row width increased (Taylor, 1980; Beatty et al., 1982; Alessi and Power, 1982); however, increases in pod number per plant are offset by decreased seed size, minimizing yield response. Other studies have indicated no change in pods per plant over a wide range of row spacings (Hicks et al., 1969; Ethredge et al., 1989). Ethredge et al. (1989) found that all row spacings had an equal number of pods per plant but the narrow rows were able to out-yield the wide rows due to a higher plant survival rate. In 1992, Board et al. found no interaction between row spacing and seeds per pod or seed size. They also concluded that increased yields in narrow rows were due to greater plant survival and less pod abortion.

Plant population influence on soybean yield components has produced consistent results. Many studies have concluded that an increase in plant population will result in a decrease in pods per plant (Lehman and Lambert, 1960; Hicks et al., 1969; Lueschen and Hicks, 1977; Alessi and Power, 1982; Carpenter and Board, 1997). Many studies also have concluded that as plant population decreased, seeds per pod increased (Lehman and Lambert, 1960; Fontes and Ohlrogge, 1972; Basnet et al., 1974; Lueschen and Hicks, 1977). Other studies have shown that plant population has little influence on seeds per pod (Board et al., 1992; Carpenter and Board, 1997).

Soybean plant population also can affect seed weight. Some studies have concluded that as plant population decreased, seed weight increased (Weber et al., 1966; Wright et al., 1984; Moore, 1991; Wells, 1993). Elmore (1998) found that seed weight was increased with a decrease in plant population for determinate cultivars but found no seed weight by plant population interaction with indeterminate cultivars. In Wisconsin, Costa et al. (1980) reported results that differed from these studies. Their results indicated that as plant population increased, the number of branches was drastically decreased and seed weight increased.

Effects of Soybean Row Spacing and Seeding Rate on Lodging

Soybean lodging can significantly increase harvest losses and be detrimental to the crop's yield potential. Many studies have indicated yield reductions due to natural plant lodging (Weber and Fehr, 1966; Cooper, 1971a; Beaver and Johnson, 1981). Row spacing has been shown to affect soybean lodging. Some studies have indicated that an increase in lodging can be seen when row widths are decreased (Hicks et al., 1969; Cooper, 1971b; Caviness et al., 1987). Other research has shown that lodging increases as row width increases (Cooper, 1970; Wykle, 1997). In 1984, Bharati found that row spacing had no effect on lodging.

Seeding rate and plant population can also influence lodging. Studies consistently have shown that increases in plant population increase the occurrence and severity of lodging (Fontes and Ohlrogge, 1972; Costa et al., 1980; Beaver and Johnson, 1981; Moore, 1991; Wykle, 1997). In Indiana, Wilcox (1974) conducted a study using three cultivars and 14 plant populations ranging from 25,000 to 582,000 seeds per hectare. He found that as the plant population increased, lodging increased as well. This increase occurred for all three cultivars; however, severity of lodging differed by cultivar.

MATERIALS AND METHODS

This experiment was conducted during the 1998 and 1999 growing seasons at the Iowa State University Sorenson Research Farm located southwest of Ames, Iowa. An additional experiment was conducted during the 1999 growing season at the Iowa State University Northeast Research and Demonstration Farm located southwest of Nashua, Iowa.

The experimental design for both locations was a randomized complete block with a split plot and four replications of each treatment. The treatments were a combination of three planting dates, three row spacings, and three seeding rate. The main plot treatments were planting date, with nine row width-seeding rate combinations serving as the completely randomized subplot treatments.

Ames 1998 and 1999

The soil type at the Sorenson Farm consists of a Clarion-Nicollet-Webster soil complex. Soil tests indicated optimal phosphorus, potassium, and pH levels for both growing seasons. Soil tests also indicated that soybean cyst nematode population densities were low and probably did not influence the seed yield in either season. The cropping history of the site consisted of a corn-soybean crop rotation. The previous crop in both years was corn [*Zea mays* (L.)], which was harvested for grain. The stalks were chopped after harvest but no fall or spring tillage was performed. The soybeans were planted into a no-till seedbed.

In each season, three planting dates (considered "early", "medium", and "late") were compared. In 1998, planting dates were 5 May, 19 May, and 24 June. In 1999, planting dates were 3 May, 25 May, and 17 June. Three row widths were compared in this study: 19-, 38-, and 76-cm. A White 6100 air planter with a 6900 series splitter attachment was used to plant the 38- and 76-cm rows. A John Deere model 750 no-till drill was used to plant the 19-cm rows. Three seeding rates (low, medium, and high) were compared in the study. The seeding rates were 296,400, 395,200, and 494,000 seeds per hectare.

In both years, Stine 2686 cultivar with a relative maturity of 2.6 was evaluated. It was selected based on its previous high yield performance in the Iowa Crop Performance Test – Soybeans (Voss and Schlafke, 1997). All experimental plots were 13.7 meters (m) in length. The 38- and 76-cm row plots were 4.6-m (eleven and six rows, respectively) wide. The 19-cm row plots were 3-m (16 rows) wide.

In 1998, a preplant application of flumetsulam (0.07 kilograms active ingredient per hectare (kg ai/ha)) and metolachlor (2.62 kg ai/ha) was applied preplant to the experimental site. Glyphosate (0.56 kg ai/ha) and metribuzin (0.28 kg ai/ha) were also applied to the experimental site on 1 May. A post-emergence application of bentazon (0.84 kg ai/ha), acifluorfen (0.19 kg ai/ha), and sethoxydim (0.21 kg ai/ha) plus 2.34 liters per hectare (l/ha) of crop oil concentrate was applied on 10 July. In 1999, preplant applications (1 May) were the same as those made in 1998. They were followed by a post emergence application of sethoxydim (0.21 kg ai/ha) plus 2.34 l/ha of crop oil concentrate on 29 June. Supplemental hand weeding was performed in both seasons, as needed.

Plant population estimates were taken between vegetative development stages V2-V4 and at the late reproductive development stage R8 in each season (Ritchie et al., 1992). Plant population estimates were achieved by counting the number of plants in 2.65-m of row length at six arbitrarily selected locations within a plot. These figures were averaged, and plant populations were estimated mathematically. The 2.65-m measurement equaled 1/4942, 1/9884, and 1/19,768 of a hectare for 76-, 38-, and 19-cm rows, respectively. Target plant populations were 80-85% of the seeding rates or 245,000 (low), 320,000 (medium), and 395,000 (high) plants per hectare.

Dates for attaining developmental stages VC, R1, and R8 were recorded for each planting date in both seasons. A plot was considered to be at a specific development stage when 50% of the plants had reached that stage. In both seasons, the only variable that affected the rate of maturity was planting date. Dates for which each treatment reached these developmental stages for each season and each planting date are presented in the Appendix.

Plant height, measured from the soil surface to the terminal pod of the top node on the main stem, was recorded for all treatments at physiological maturity (R8). An average height was calculated for each plot and treatment. Soybean yield components were calculated in both seasons as well. In both seasons, the number of pods per plant was estimated by sampling 10 arbitrarily selected plants from non-harvest rows for each plot. Pods containing at least one seed were counted for each of the ten plants. Plant lodging also was scored but showed no significant response to the different treatments; therefore, lodging results are excluded from this thesis. Average pods per plant were calculated for each plot and treatment. In 1999, seeds per pod were calculated using the same 10 plants used to determine the number of pods per plant. Five pods were arbitrarily selected from each of the 10 plants, and the pods containing 1, 2, 3, and 4 seeds were separated and counted. Seeds per pod data are excluded from this thesis due to the lack of response to different treatments. In both years, seed weight was measured and corrected to 13% moisture for each plot. Seeds per kilogram and 100-seed weights also were recorded using an electronic seed counter and scale.

Plots were harvested with an Almaco PCM-10 plot combine. The combine harvested a 1.52-m section (7, 4, and 2 rows for the 19-, 38-, and 76-cm rows, respectively) from the middle of each plot. In 1998, plots were harvested on 29 September (Dates 1 and 2 of Replication 4 and Date 2 of Replication 3), 9 October (remaining Date 1 and 2 plots), and October 15 (all Date 3 plots). Maturity, equipment breakdown, and precipitation delays affected harvest dates. In 1999, all plots were harvested on 10 October. Grain samples were weighed as stated above and sub-sampled for seed composition (seed protein and oil percentages) analysis. Seed composition figures for both seasons are presented in the Appendix.

Nashua 1999

Soils at the Northeast Research and Demonstration Farm near Nashua are typical of the Kenyon-Floyd-Clyde soil association. Soil tests indicated optimal phosphorus, potassium, and pH levels for the growing season. The cropping history consisted of a corn-soybean crop rotation. The previous crop was corn [*Zea mays* (L.)], which was harvested for grain. The entire experiment area was chisel plowed in the fall. Planting date blocks were field cultivated the day before each planting.

Three planting dates were evaluated, including an "early", "medium", and "late" planting. Planting dates were 26 April, 26 May, and 21 June. Three row widths were compared in the study: 25-, 51-, and 76-cm. An Almaco 8000 series "Quick Change" cone-type grain drill was used to plant all three row spacings. Three seeding rates (low, medium, and high) were compared in this study. The seeding rates were 247,000, 402,610, and 555,750 seeds per hectare. The seeding rates were achieved by using pre-packaged seed.

In this study, Asgrow AG2301 with glyphosate resistance and relative maturity of 2.3 was the cultivar used. It was selected based on its previous high yield performance in the Iowa Crop Performance Test – Soybeans (Voss and Schlafke, 1997). The increased number of glyphosate tolerant cultivars used in Iowa also was considered when making the cultivar selection. The increase in acreage planted with glyphosate-resistant cultivars has increased producers' interest in whether or not these cultivars react the same as conventional cultivars in different management schemes. All experimental plots were 16.8-m in length. The drill planted 4, 5, and 10 rows for 76-, 51-, and 25-cm rows, respectively. Each plot consisted of two passes with the drill, or 8, 10, and 20 rows for 76-, 51-, and 25-cm rows, respectively.

On 26 June, a post-emergence application of glyphosate (1.12 kg ai/ha) was applied to the first two planting dates. On 27 July a post-emergence application of glyphosate (1.12 kg ai/ha) was applied to the third planting date. There were no pre-emergence herbicide applications made to the experimental area.

Plant population estimates were taken at an early vegetative development stage (V4) and a late reproductive development stage (R8). Plant population estimates were achieved by counting the number of plants in 2.65-m of row length, at six arbitrarily selected locations within a plot. These figures were averaged, and plant populations were estimated mathematically. The 2.65-m measurement equaled 1/4942, 1/7413, and 1/14,826 of a hectare for 76-, 51-, and 25-cm rows respectively. Targeted plant populations were 80-85% of the seeding rate or 205,000 (low), 325,000 (medium), and 445,000 (high) plants per hectare.

Dates for attaining developmental stages VC, R1, and R8 were recorded for each planting date. A plot was considered to be at a specific developement stage when 50% of the plants had reached that stage. The only variable that affected the rate of maturity was planting date. Dates for which each treatment reached these developmental stages at each planting date are presented in the Appendix.

Plant height and soybean yield components (pods per plant, seeds per pod, plot seed weight, weight per 100 seeds) were recorded using the same techniques discussed previously for the location near Ames.

Plots were harvested with a John Deere model 4400 combine. The combine harvested a 3.81-m section (15, 7, and 5 rows for the 25-, 51-, and 76-cm rows, respectively) from the center of each plot. All plots were harvested with grain samples collected on 11 October. Plot yield was weighed in the combine, and sub-samples were taken from each plot after plot seed weight was figured. Grain samples were analyzed for seed composition. Seed composition figures are presented in the Appendix.

The addition of this experiment in 1999 was intended to see how glyphosate resistant cultivars performed when influenced by planting date, plant population, and row spacing variables. It also was intended to test more extreme levels (high and low) of plant population and planting date. No direct statistical comparisons were made between this experiment and the one conducted near Ames.

Statistical Analysis

The experimental design for both locations was a randomized complete block with split-plots. The treatments were a combination of three planting dates, three row spacings, and three plant populations. The main plot treatments were planting date, with nine row width-plant population combinations serving as the completely randomized subplot treatments. There were four replications of each treatment.

Analyses of variance were conducted for yields, plant heights, and yield components on planting dates, row spacings, and plant populations to determine statistical differences among treatments. Analyses were done on individual and combined years data. Treatment means from each individual year were used as data in order to obtain the combined analysis. All data presented in this thesis, unless otherwise noted, were tested at the ($P = 0.05$) level for significant responses.

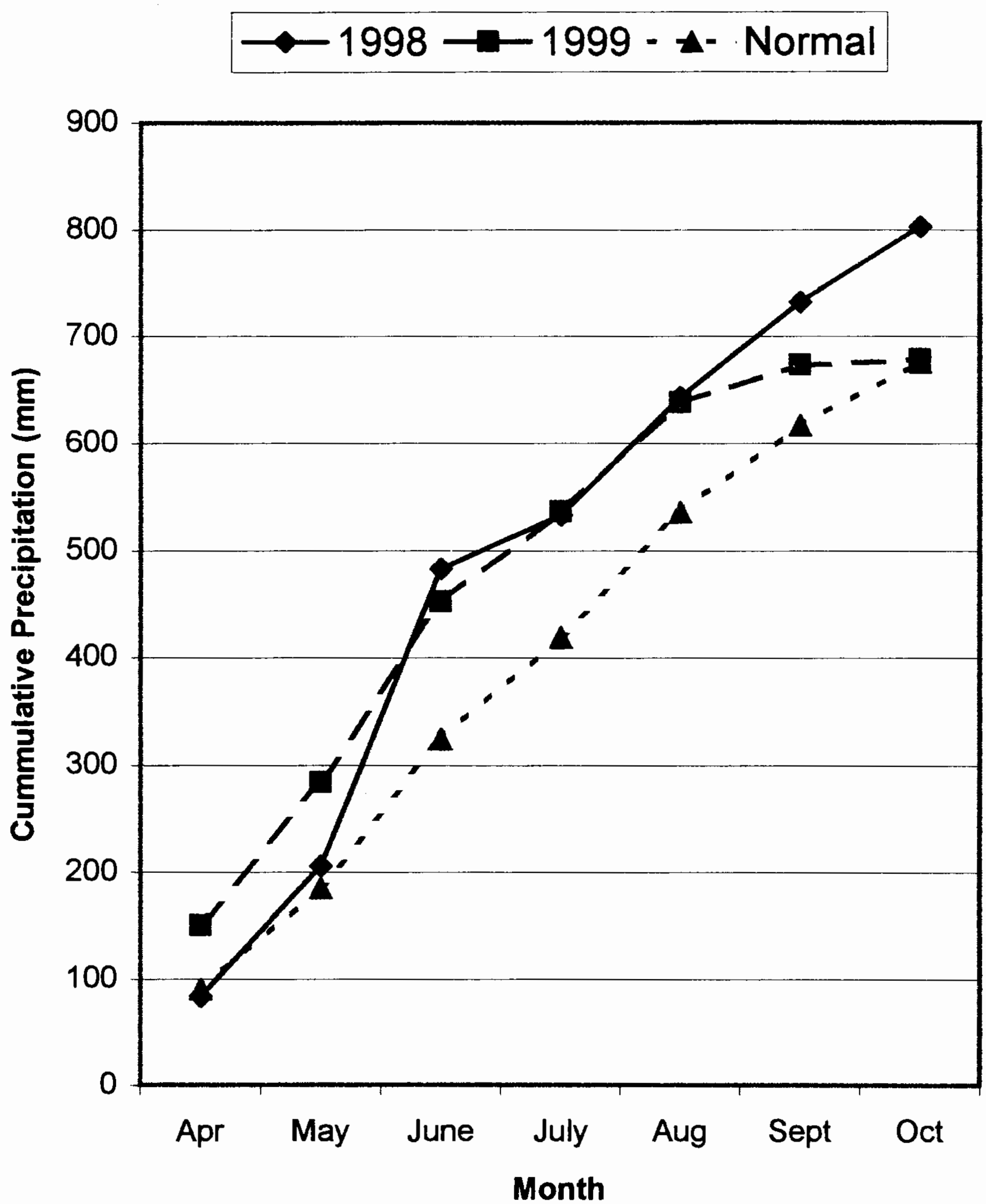
RESULTS AND DISCUSSION

Ames 1998 and 1999

Summary of season growing conditions

The 1998 growing season was characterized by above normal precipitation during all months of the growing season. Following a moist but fairly mild winter, spring brought some uncharacteristically cold temperatures and unfavorable precipitation patterns. Precipitation for 1998, 1999, and the normal (30-year average) are shown in Figure 1. April 1998 began with high rainfall and very cool temperatures creating difficulty for many producers to begin spring fieldwork. Temperatures returned to normal towards the end of April, drying the ground and providing a narrow window between late April and early May in which planting was able to begin. Mid to late May provided the young crops with warm conditions allowing rapid early growth. A good portion of the crops planted in May emerged within one week of planting. June had some uncharacteristically low temperatures and above normal rainfall. Storms were causing problems with the newly emerged crops and making it very difficult to complete late season planting. August and September were fairly consistent with the normal monthly rainfall for the area, although total water supplies were above normal as a result of the heavy June rainfall. Crop maturity progressed rapidly with above normal September temperatures and harvest began in late September.

The 1999 growing season began similar to the 1998 season, but conditions remained unfavorable for a longer period in 1999 than 1998, resulting in slower emergence and growth. April was the wettest for Iowa in more than 127 years (Iowa Agricultural Statistics, 1999). Fieldwork was, for the most part, non-existent in April. A narrow window of warm



* Adapted from Iowa Agricultural Statistics Reports

Figure 1. Normal (30-year average), 1998, and 1999 cummulative precipitation for Central Iowa.

and dry conditions came in early May. Many producers were able to begin planting at this time. Storms and heavy rains followed in mid-May. These conditions caused further delays in planting, especially for soybeans. Producers had another window to work in from late May to mid-June. Cool and wet conditions in late June caused stressful germination and emergence conditions for late planted crops and some disease pressure for crops planted earlier in the season. Warm and dry conditions in August and September limited moisture availability during the grain-filling stages and may have been the primary cause for reduced soybean yields (Sionit and Kramer, 1977; Farnham, 2000).

Yield

Average soybean yields for this study, as shown in Figure 2, differed significantly between 1998 and 1999. The 1999 average yield was 17% less than the 1998 average yield (Figure 2). Individual treatment seed yield means are summarized for 1998 and 1999 in Table 1.

Main effects of planting date on soybean yield

Planting date significantly affected soybean yield in both 1998 and 1999 when averaged across all row spacings and plant populations. Planting delays reduced soybean yield potential; however, the yield reduction was not statistically significant until delays extended beyond late May in both 1998 and 1999 (Figure 3). In 1998, soybeans planted early (5 May) produced the greatest yield of 3932 kg/ha. Soybeans planted on the second planting date (19 May) produced 3691 kg/ha, an average statistically similar to the "early date" average. The 1999 results were similar. The greatest seed yields were associated with the 3 May planting date, with a yield reduction of 6% when planting date was delayed to 25

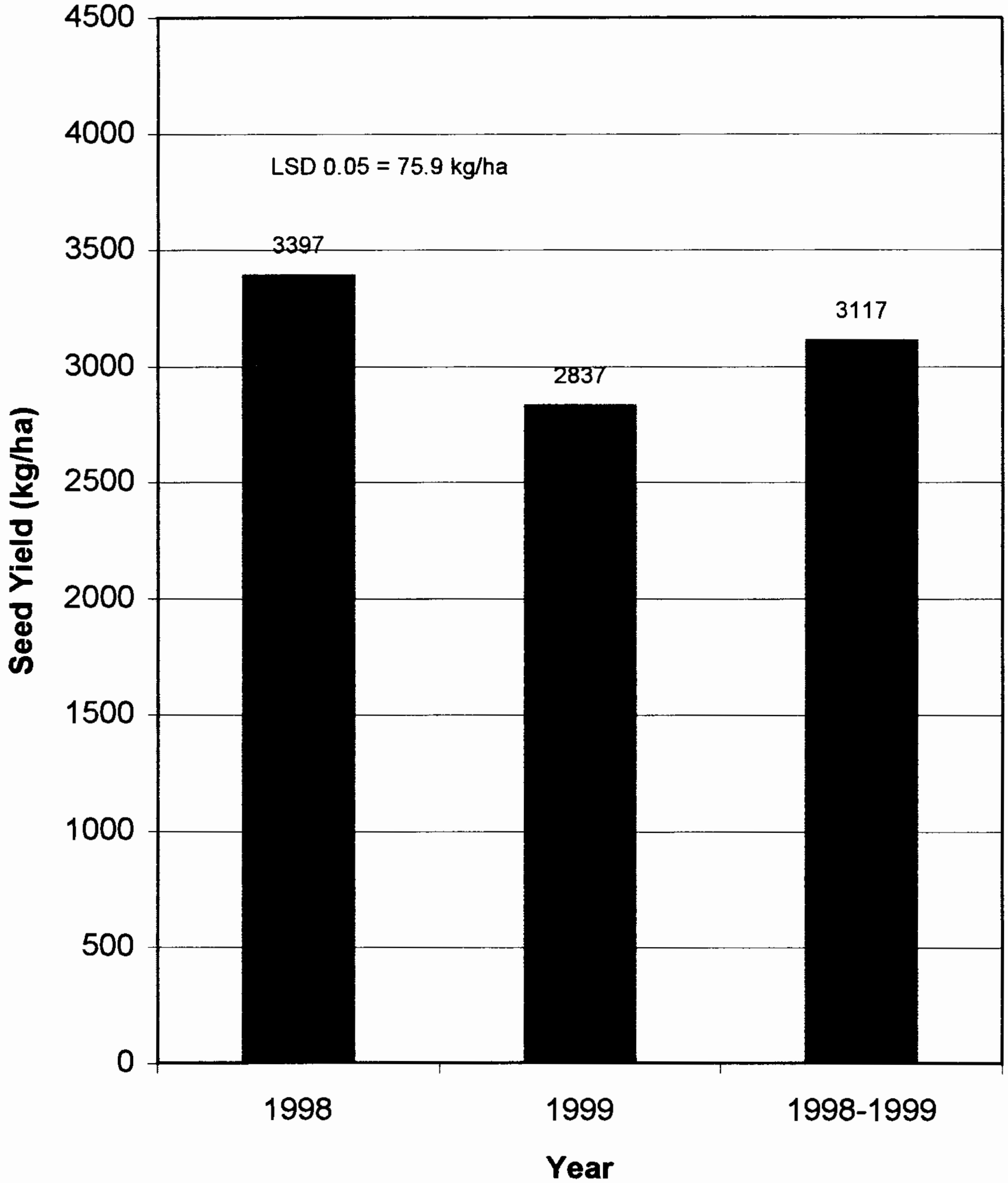


Figure 2. Yields averaged over all planting dates, plant populations, and row spacings at the Ames location (1998, 1999, and two-year average).

Table 1. Mean yields and harvest plant populations for each treatment in Ames, 1998 and 1999.

Treatment	Mean Treatment Yields		Actual Harvest Plant Populations	
	kg/ha	kg/h	plants/ha	plants/ha
Date 1	1998	1999	1998	1999
19-cm Low[1]	3644	3160	234,650	293,930
19-cm Med	3375	3596	298,870	355,680
19-cm High	3677	3596	321,100	407,550
38-cm Low	4107	3180	254,410	256,880
38-cm Med	4222	3065	306,280	301,340
38-cm High	4080	3166	355,680	360,620
76-cm Low	4067	3059	254,410	234,650
76-cm Med	4074	2971	288,990	303,810
76-cm High	4154	3105	326,040	370,500
Date 2				
19-cm Low	3018	3153	291,460	256,880
19-cm Med	3489	2870	303,810	330,980
19-cm High	3529	3099	343,330	397,670
38-cm Low	3744	3052	244,530	274,170
38-cm Med	4013	3065	306,280	328,510
38-cm High	3791	3059	380,380	405,080
76-cm Low	3825	3025	254,410	244,530
76-cm Med	4020	2850	296,400	321,100
76-cm High	3765	3072	343,330	395,200
Date 3				
19-cm Low	2333	1795	217,360	264,290
19-cm Med	2306	2494	276,640	333,450
19-cm High	2454	2171	311,220	395,200
38-cm Low	2507	2306	232,180	239,590
38-cm Med	3025	2400	298,870	296,400
38-cm High	2857	2487	316,160	353,210
76-cm Low	2622	2245	227,240	229,710
76-cm Med	2817	2561	291,460	318,630
76-cm High	3052	2178	298,870	353,210

[1]Seeding rates were 296,400 plants/ha (Low), 395,200 plants/ha (Med), and 494,000 plants/ha (High).

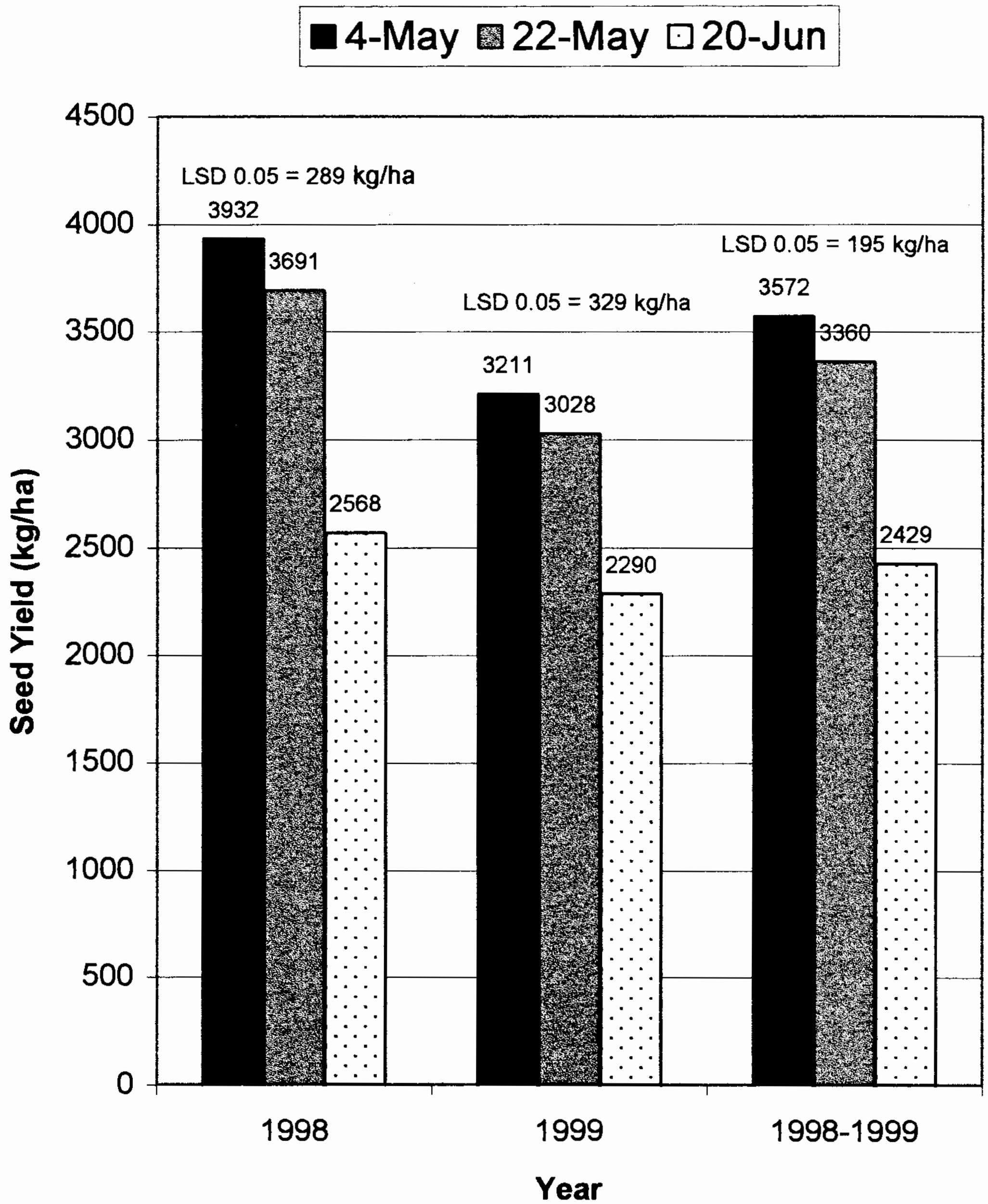


Figure 3. Mean yields for planting dates averaged over three plant populations and three row spacings at the Ames location (1998, 1999, and 1998-1999).

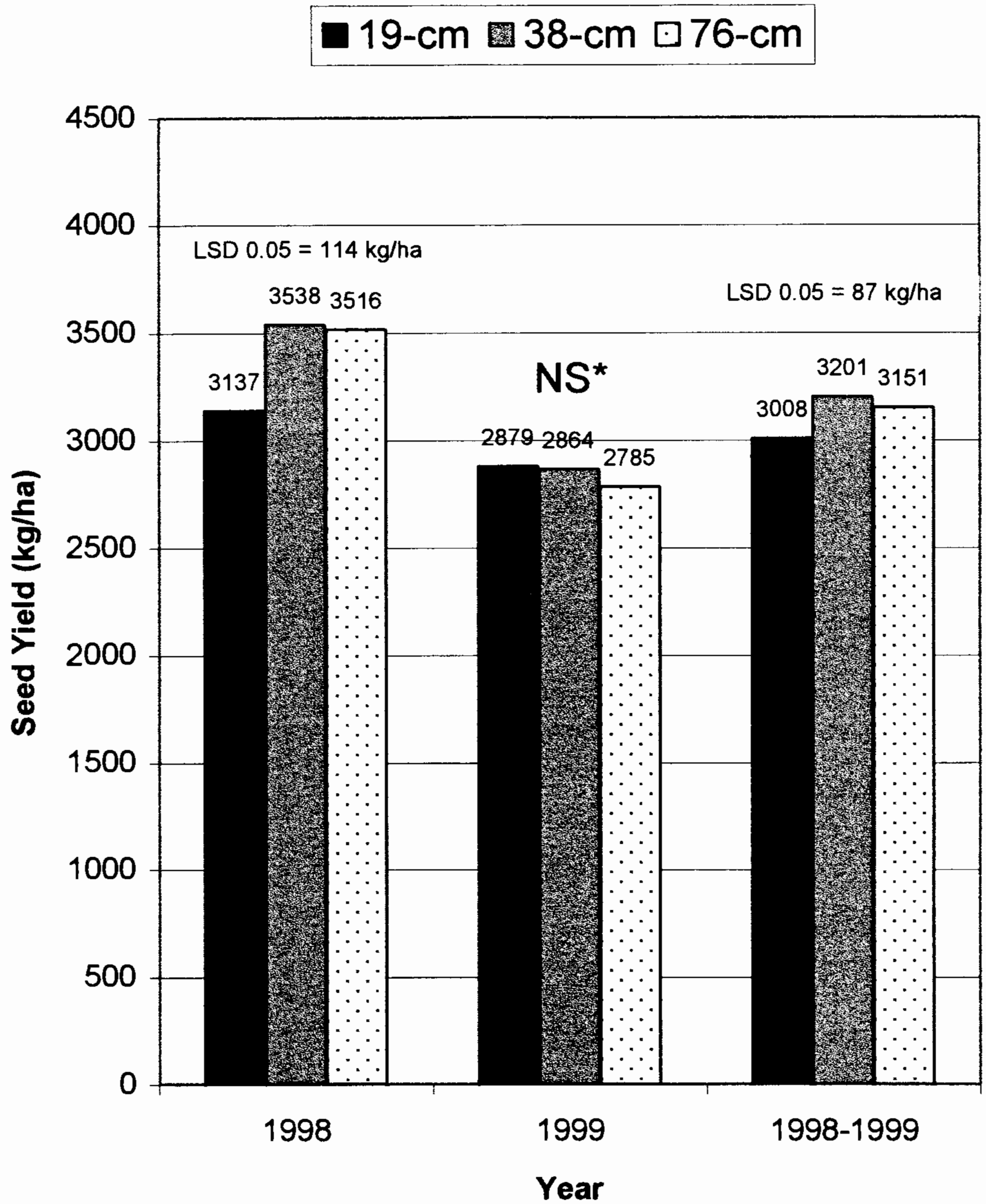
May; however, this yield decline was not statistically significant. The results from this experiment were similar to some found in past studies. In Wisconsin, Grau et al. (1994) found that a delay in planting from 1 May to 15 May also resulted in a 6% yield decrease.

In both seasons, the second delay in planting resulted in statistically significant yield reductions (Figure 3). In 1998, the third planting date (24 June) produced an average yield of 2568 kg/ha, an average 30 and 35% lower than Dates One and Two, respectively. Again, the 1999 results were similar in terms of percentage. The third planting date (17 June) produced an average yield of 2290 kg/ha a figure 25 and 30% lower than Dates One and Two, respectively. Several other Midwest studies have shown that mid-June and later planting dates can severely hinder yield potential (Anderson and Vasilas, 1985; Oplinger and Philbrook, 1992; Lundvall and Whigham, 1999).

Planting date was had an even greater effect on soybean yield when the two years of data were combined (Figure 3). There was a statistically significant yield reduction associated with each delay in planting. Date One produced the highest two-year average yield (3572 kg/ha) followed by Date Two (3360 kg/ha) and Date Three (2429 kg/ha), respectively.

Main effects of row spacing on soybean yield

The significance of row spacing on soybean seed yield, when averaged across all planting dates and plant populations, varied between the two growing seasons (Figure 4). In 1998, the 38- and 76-cm rows produced statistically similar yields. In the same year, the 19-cm rows, however, produced yields statistically lower than the 38- and 76-cm rows. The 19-cm rows produced an average yield of 3137 kg/ha, 11% less than the 38- and 76-cm rows,



*NS denotes no significant statistical difference at the (P=0.05) level.

Figure 4. Mean yields for row spacings averaged over three planting dates and three plant populations at the Ames location (1998, 1999, and 1998-1999).

which produced 3538 kg/ha and 3516 kg/ha, respectively. In 1999, there was not a significant row spacing main effect on yield (Figure 4).

Results averaged across years were similar to the 1998 individual season effects. There were no significant differences in yield for the 38- and 76-cm rows; however, the 19-cm rows produced yields that were significantly lower than the other two row spacings (Figure 4).

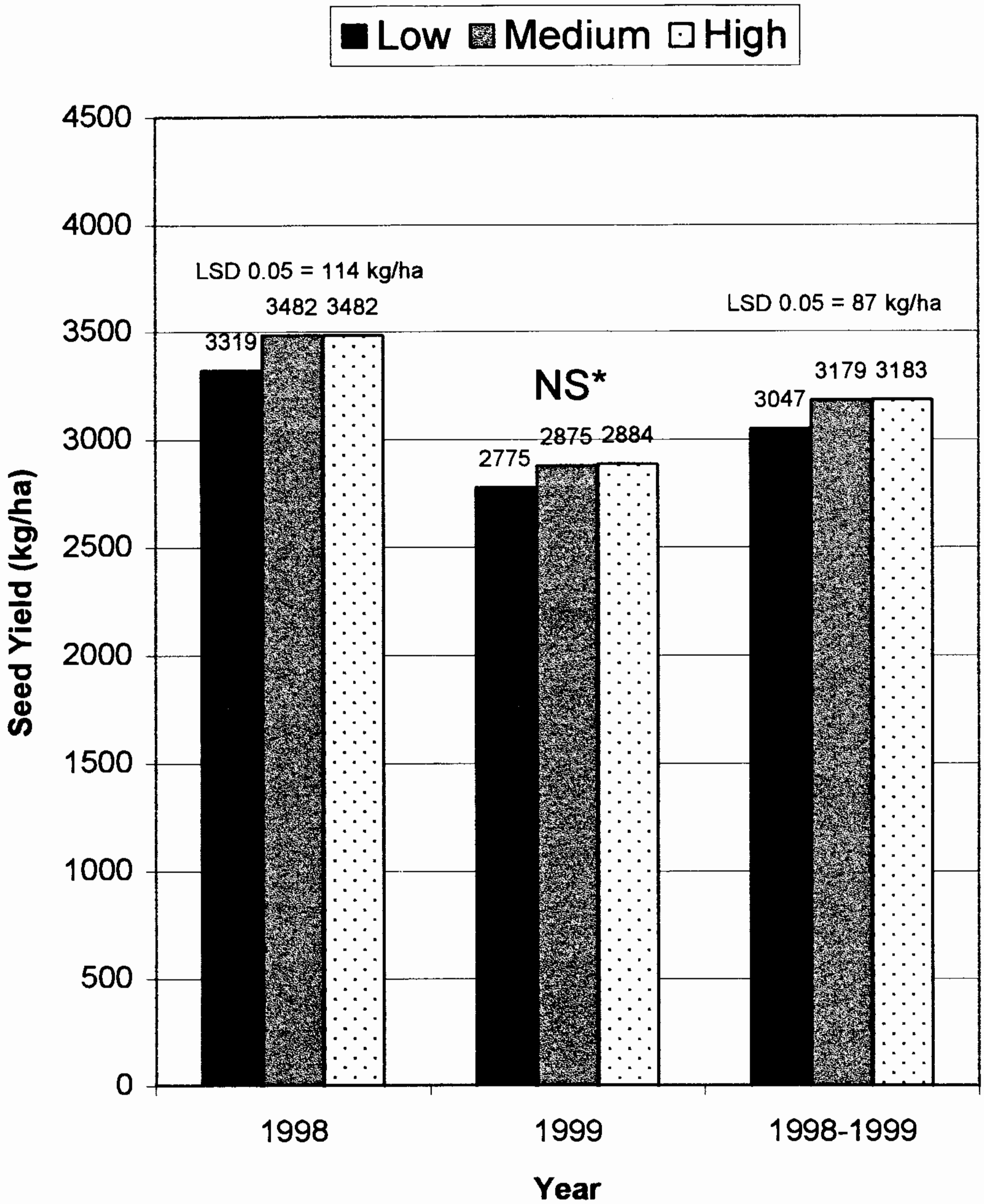
The row spacing results in this study differ from several of the studies conducted in the past. Many researchers have reported an increase in yield as row spacing decreases (Cooper, 1977; Beuerlein, 1988; Hugie and Orf, 1989). Very few studies have indicated either a yield advantage for wider rows or no significant difference to a large range of row spacings. In a recent study in Iowa, however, Wykle (1997) found no significant differences in yields for soybeans seeded in 19-, 38-, and 76-cm rows. In 1998, Elmore reported that 51-cm rows produced higher yields than did 25-cm rows. He stated excessive moisture stress causing pathogenic problems as the primary reason. It is believed that in this experiment, the primary reason for the reduced yields in the 19-cm row treatments was more directly related to plant population problems than to row spacing. The drilled plots in this study did not reach desired harvest stands (Table 1), and plant spacing was highly variable. Further discussion on this subject is included in the plant population section.

Main effects of seeding rate on soybean yield

When averaged over all planting dates and row spacings, seeding rate effects on yield were similar to the row spacing effect on yield in this study. In 1998, there was no statistical difference in the yields produced by the medium (395,200 seeds/ha) and high (494,000 seeds/ha) seeding rates (Figure 5). The low seeding rate (296,400 seeds/ha), however, produced a lower seed yield that was statistically different from those produced at the medium and high seeding rates. The medium and high seeding rates produced identical yield averages of 3482 kg/ha while the low seeding rate produced only 3319 kg/ha (Figure 5). Several other researchers have reported that increased seeding rates resulted in an increased yield (Oplinger and Philbrook, 1992; Delvin et al., 1995; Wykle, 1997). In 1999, there was no significant yield difference among the three seeding rates. Several studies conducted in the past also have indicated no yield differences over a wide range of seeding rates (Beuerlein, 1987; Carpenter and Board, 1997; Whigham and Lundvall, 1998).

The combined years data again resulted in the same trend as the 1998 season. The medium and high seeding rates produced nearly identical yields while the low seeding rate produced significantly lower yields (Figure 5).

Seeding rates for this study were based on a high, medium, and low level. The medium seeding rate represents the current Iowa State University Extension recommendation (Whigham, 1998). Seeding rates were selected assuming a 15-20% loss (failure of germination or premature seedling loss), targeting plant populations of 80-85% of the seeding rate. Table 1 indicates the mean for actual harvest plant population in each treatment for both seasons. Stand count results indicate that plant populations were highly variable in both seasons. Many of the plots did not achieve the target plant populations, although final plant stands were closer to the targeted stands in 1999 than in 1998. The main reason for the lower plant populations can be attributed to the cool, wet growing conditions experienced during each season. The wet conditions of the no-till seedbed made furrow closure and seed placement more difficult and resulted in less seed-to-soil contact hindering some seed



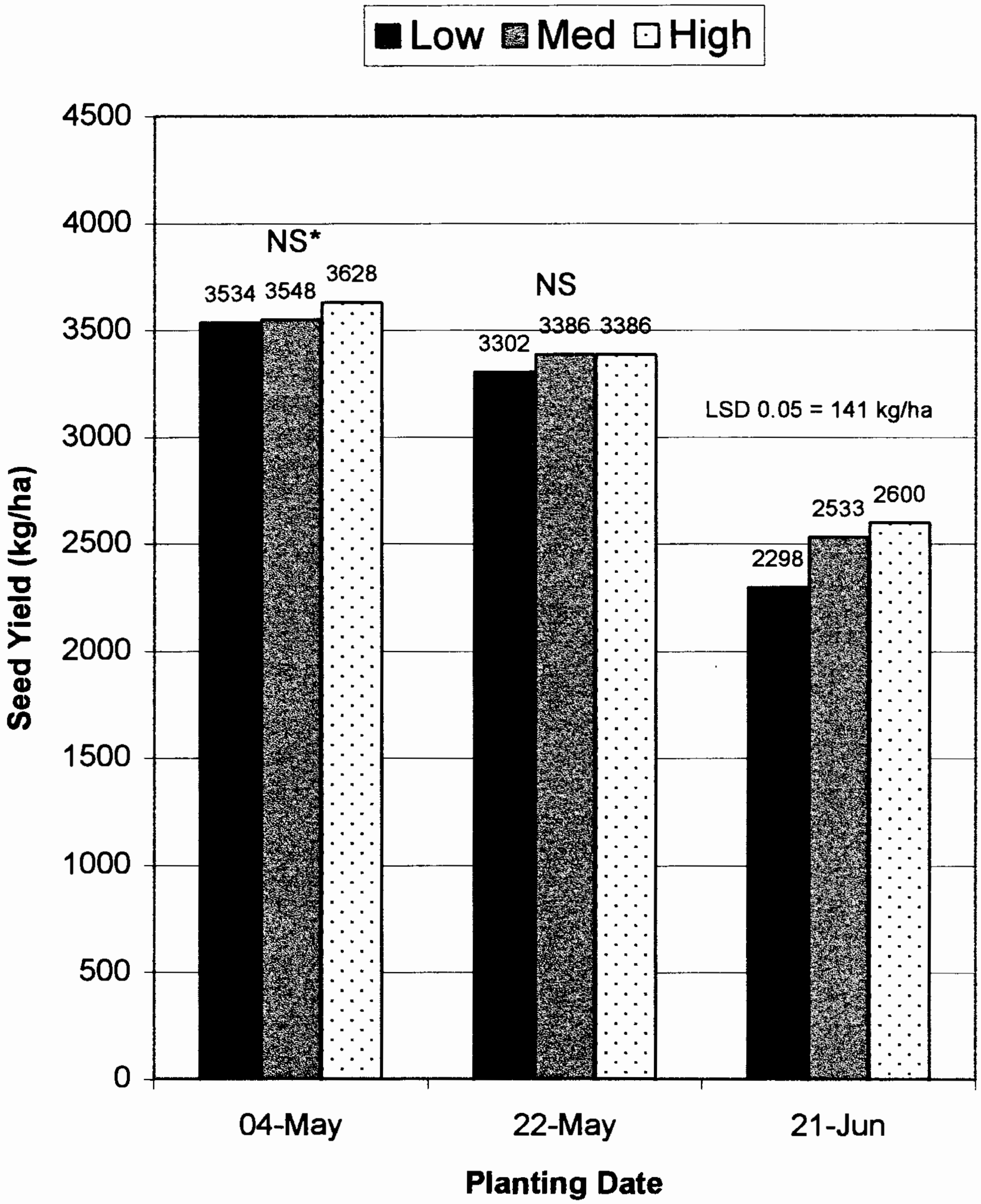
*NS denotes no significant statistical difference at the (P=0.05) level.

Figure 5. Mean yields for seeding rates averaged over three planting dates and three row spacings at the Ames location (1998, 1999, and 1998-1999).

germination. This was more of a problem with the 19-cm rows, which were seeded with the grain drill. Heavy spring rains coupled with the no-till crop residue created an unfavorable seedbed that resulted in many seeds remaining on top of the soil surface in the drilled treatments. Past studies have indicated that to achieve desired plant populations, higher seeding rates than previously recommended are necessary with no-till conditions (Oplinger and Philbrook, 1992).

Interactive effects of planting date, row spacing, and seeding rate combinations on soybean yield

Soybean seed yield response to seeding rate was influenced by planting date in each year, however, the effect was different in 1998, 1999, and in the combined years. Figure 6 shows that in the 1998-1999 combined seasons, planting date had an influence on yield response to seeding rate. Planting date did not influence yield responses to seeding rates in the first two planting dates. The late planting date, however, responded to an increase in seeding rate. A statistically significant yield increase resulted when the seeding rate was increased from the low to medium level. The additional increase to the high seeding rate level produced a yield statistically similar to the medium rate, indicating that the additional increase was not necessary to achieve top yields. These data indicate that later planting dates in soybeans may require an increase in seeding rate to reach maximum yields. Although planting date influenced the yield response to seeding rate in the combined seasons data, the overall planting date by seeding rate interaction was not statistically significant ($P = 0.12$). The 1998 and 1999 individual season planting date influence on yield responses to seeding rate differed from the combined data results. The data for the individual season planting date

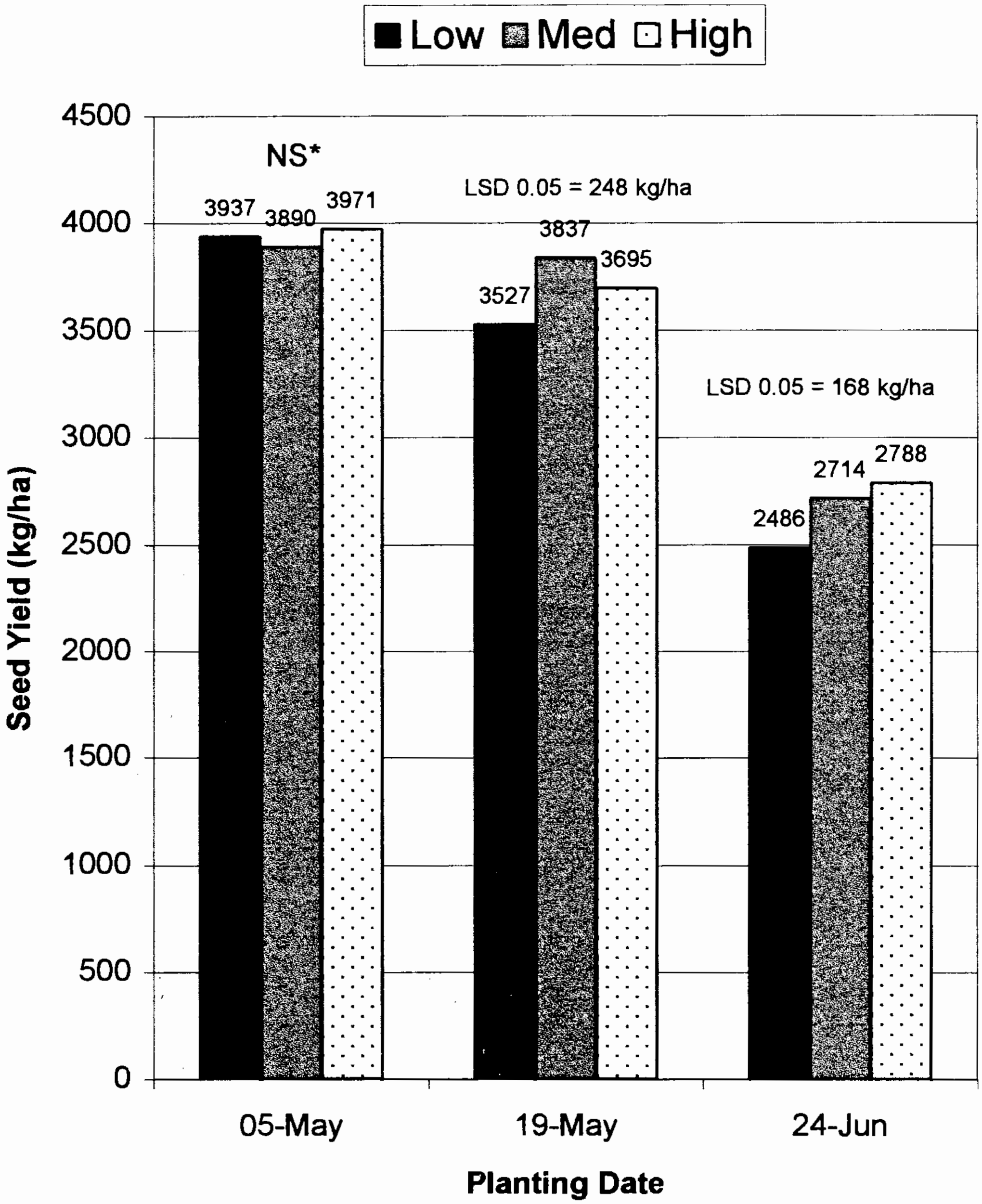


*Within a planting date,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 6. Planting date influence on soybean yield response to seeding rate at the Ames location (1998-1999).

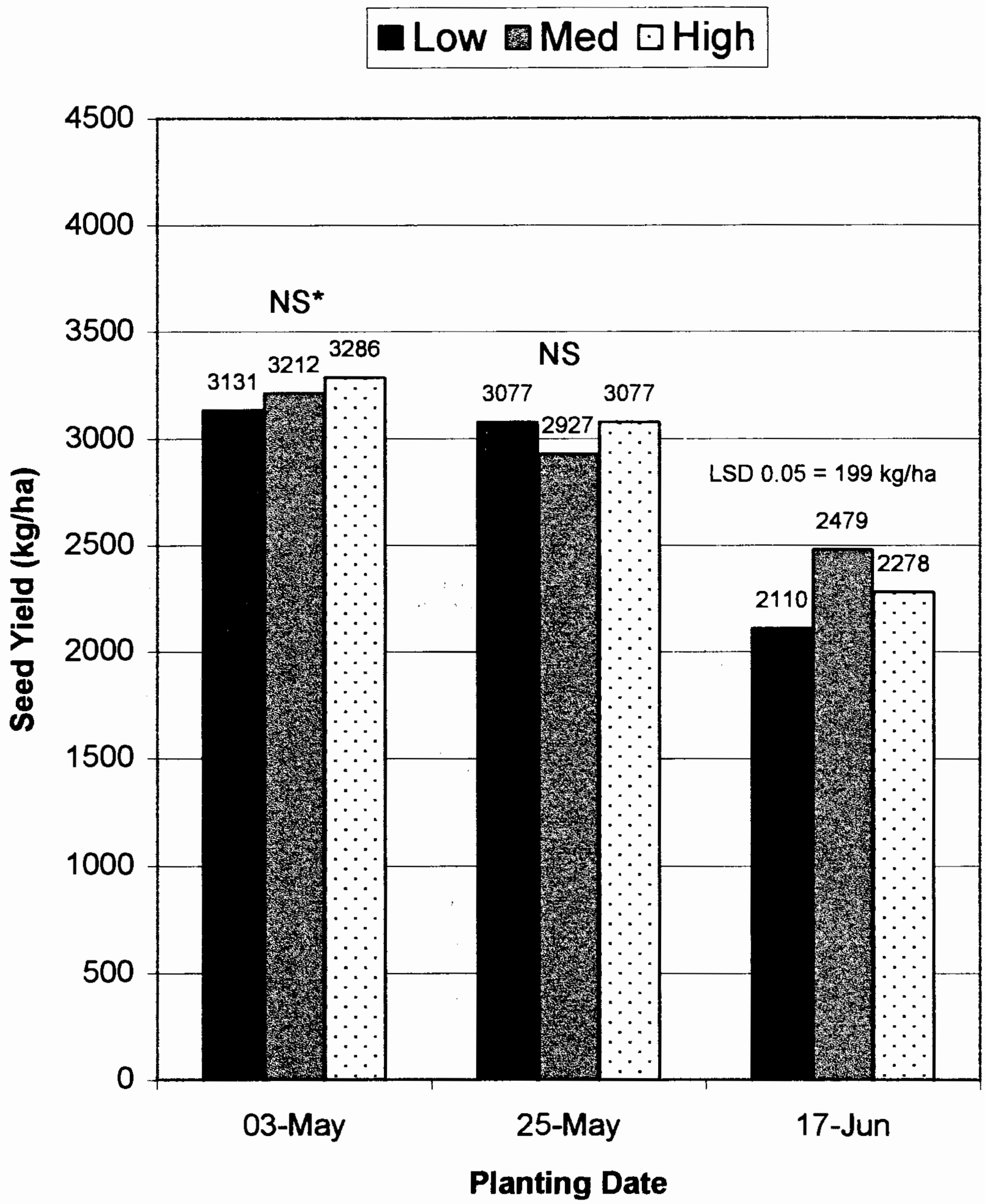
influence on yield response to seeding rates are shown in Figures 7 and 8. The 1998 season showed a yield response to seeding rate at the second and third planting dates. Again, the two dates indicated a yield increase when increasing seeding rate from the low to the medium level. No yield advantages were observed by increasing the seeding rate to the high level in 1998. In 1999, planting date again influenced the yield response to seeding rate. No yield response to seeding rate was observed in the first two planting dates, however, the third planting date responded to an increase in seeding rate from the low to medium level. In the 1999 season, the additional seeding rate increase resulted in statistically lower seed yields. Results from both the 1998 and 1999 seasons indicated a significant planting date by seeding rate interaction ($P = 0.05$ and $P = 0.01$, respectively).

Planting date also influenced the soybean yield response to row spacing. Figure 9 shows that in the combined years data, yield responses to row spacing differed among planting dates. The first planting date indicated no yield response to row spacing. The second and third planting dates, however, had a significant yield response to row spacing. These dates both produced statistically higher yields when row spacing was increased from 19-cm to 38-cm. The second planting date showed an 8% yield increase by increasing row spacing to 38-cm, while the third planting date showed a 13% yield increase with the increase in row width to 38-cm. In both the second and third planting dates, the increase in row width to 76-cm produced nearly identical yields (1% lower) to the 38-cm rows, indicating no statistical difference between the 38- and 76-cm row widths. Although there was some planting date influence on the yield response to row spacing, the overall planting date by row spacing interaction ($P = 0.17$) was not statistically significant for the combined seasons data.



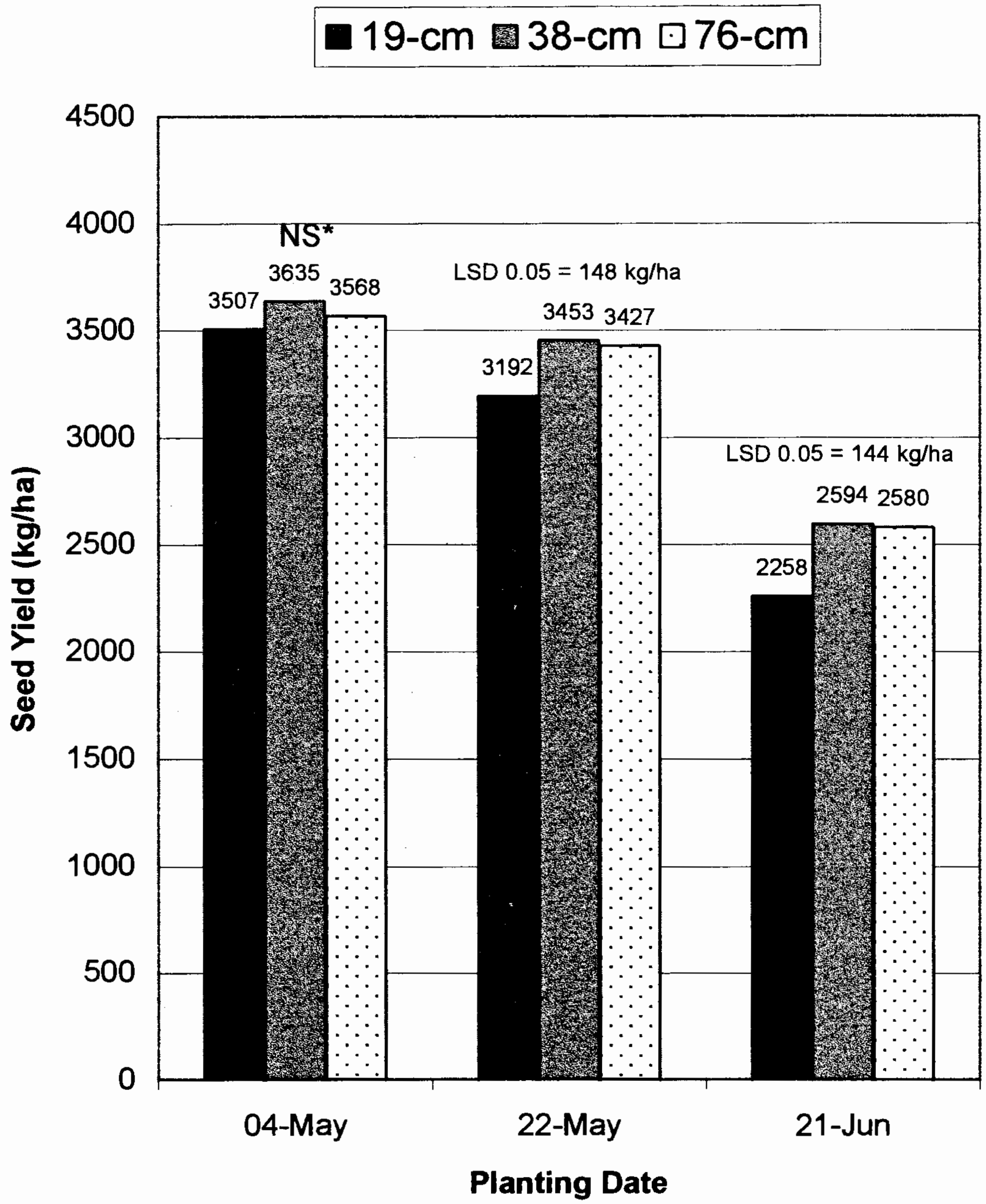
*Within a planting date,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 7. Planting date influence on soybean yield response to seeding rate at the Ames location (1998).



*Within a planting date,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 8. Planting date influence on soybean yield response to seeding rate at the Ames location (1999).



*Within a planting date,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 9. Planting date influence on soybean yield response to row spacing at the Ames location (1998-1999).

In 1998, soybean yield response to row spacing was not influenced by planting date (Figure 10). The row width effect on soybean seed yield was similar regardless of planting date, indicating the lack of a significant planting date by row spacing interaction ($P = 0.91$). The results differed in the 1999 season; the yield response to row width was influenced by planting date (Figure 11). In 1999, soybeans planted on 3 May produced statistically higher yields in 19-cm rows than in 38- and 76-cm rows. Soybeans planted on 25 May did not significantly respond to row spacing. Soybeans planted on June 17 produced top yields in 38-cm row, however, this yield was statistically similar to the yield of the 76-cm rows. The 19-cm row spacing produced yields significantly lower than the 38-cm spacing. Similar to the combined years data, the 76-cm spacing produced yields statistically similar to both the 19- and 38-cm spacings, suggesting no advantages to an additional row spacing increase. The planting date influence on seed yield response to row spacing in 1999 indicated a statistically significant ($P = 0.002$) planting date by row spacing interaction.

Figures 12-14 illustrate the row spacing influence on yield response to seeding rate. The combined season data show that row spacing did influence the soybeans yield response to seeding rate. Soybeans planted in 38- and 76-cm rows did not exhibit a significant yield response to seeding rate. Soybeans planted in 19-cm rows, however, showed a significant yield response to seeding rate. Yields were increased as seeding rate was increased. The increase from the low to medium level seeding rate produced a statistically significant yield increase; however, further seeding rate increase produced no statistical difference in yield. Although Figure 12 shows that row spacing did influence the yield response to seeding rate, the row spacing by seeding rate interaction ($P = 0.54$) for the combined seasons was not statistically significant. Figure 13 illustrates the row spacing influence on the soybean yield

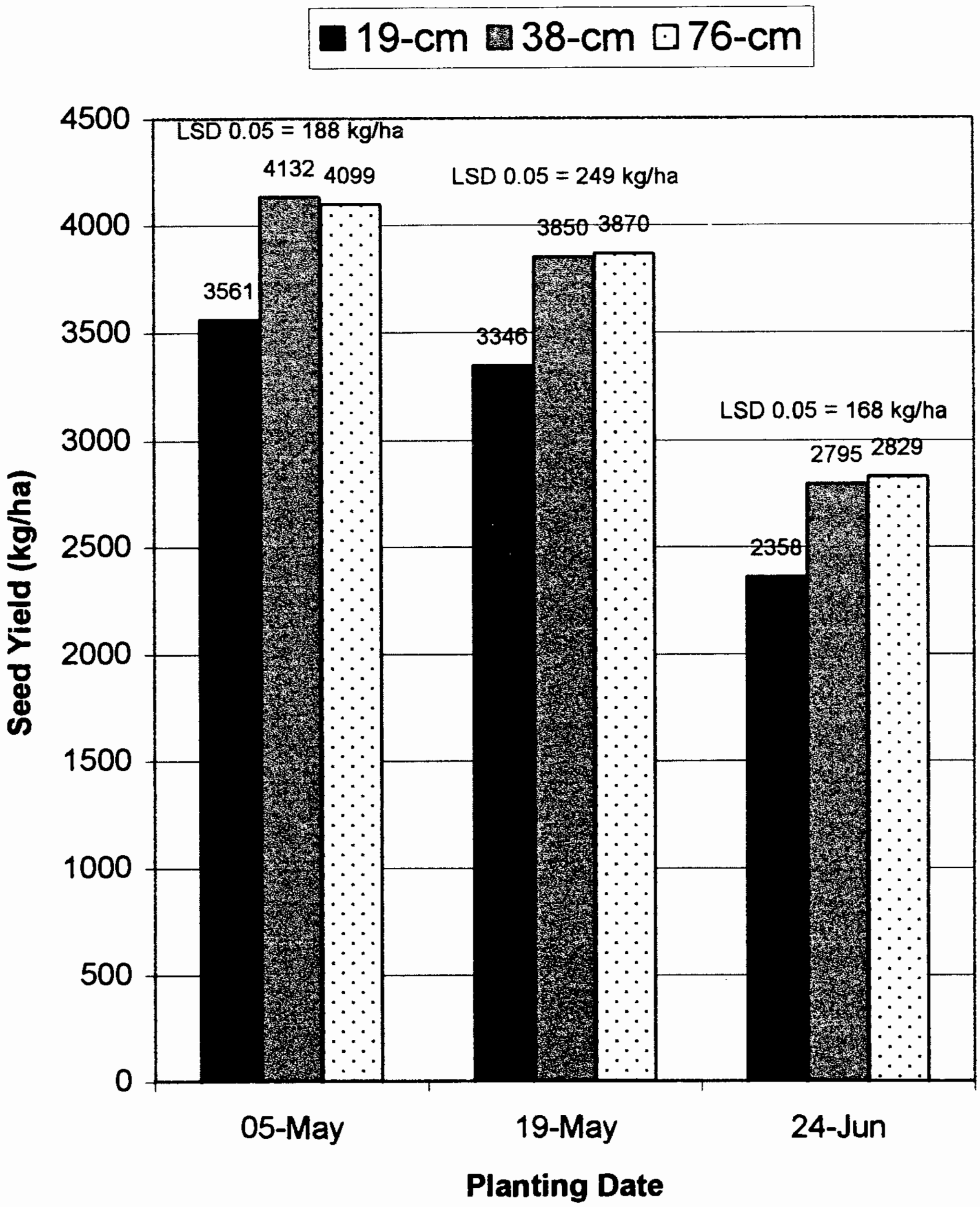
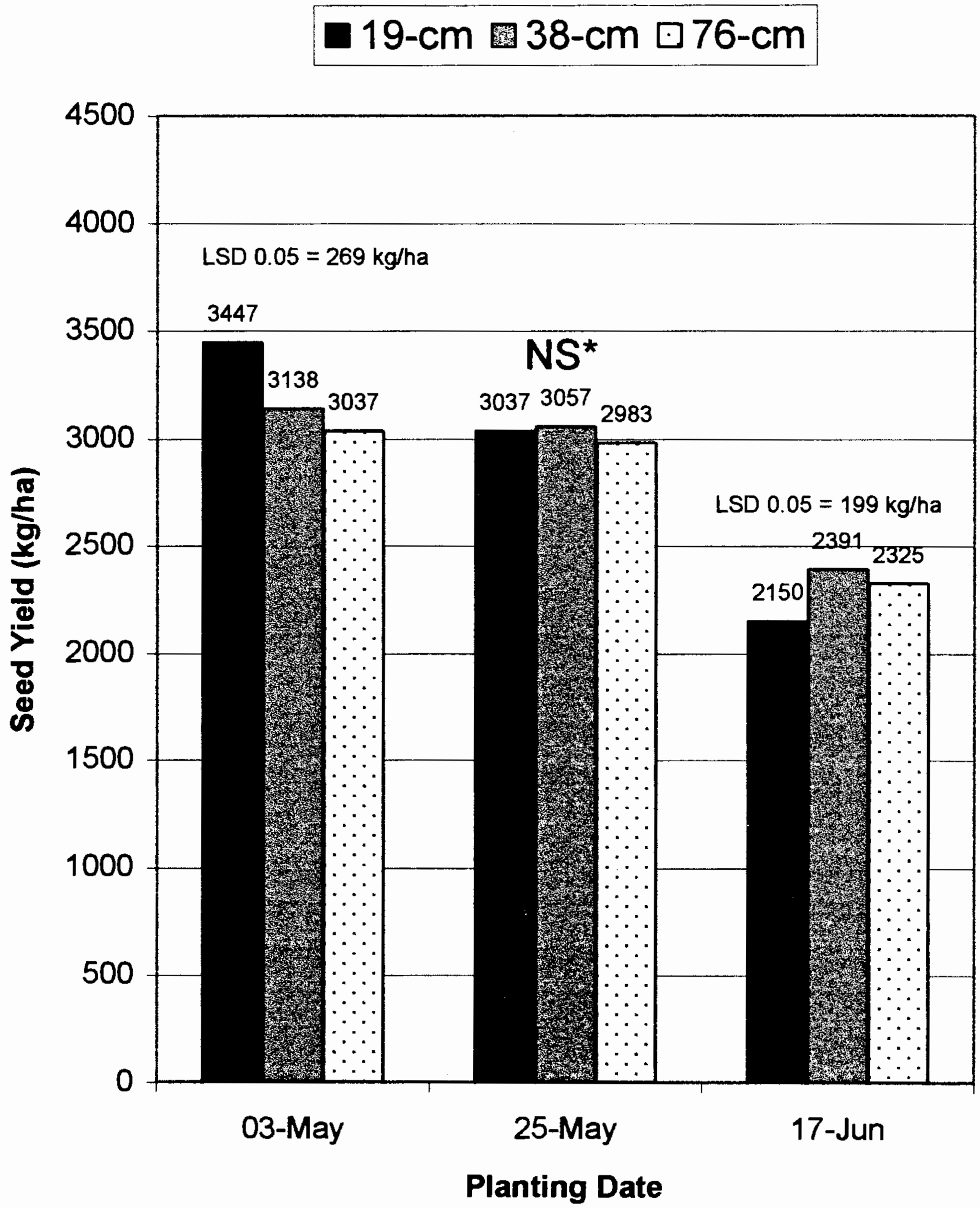
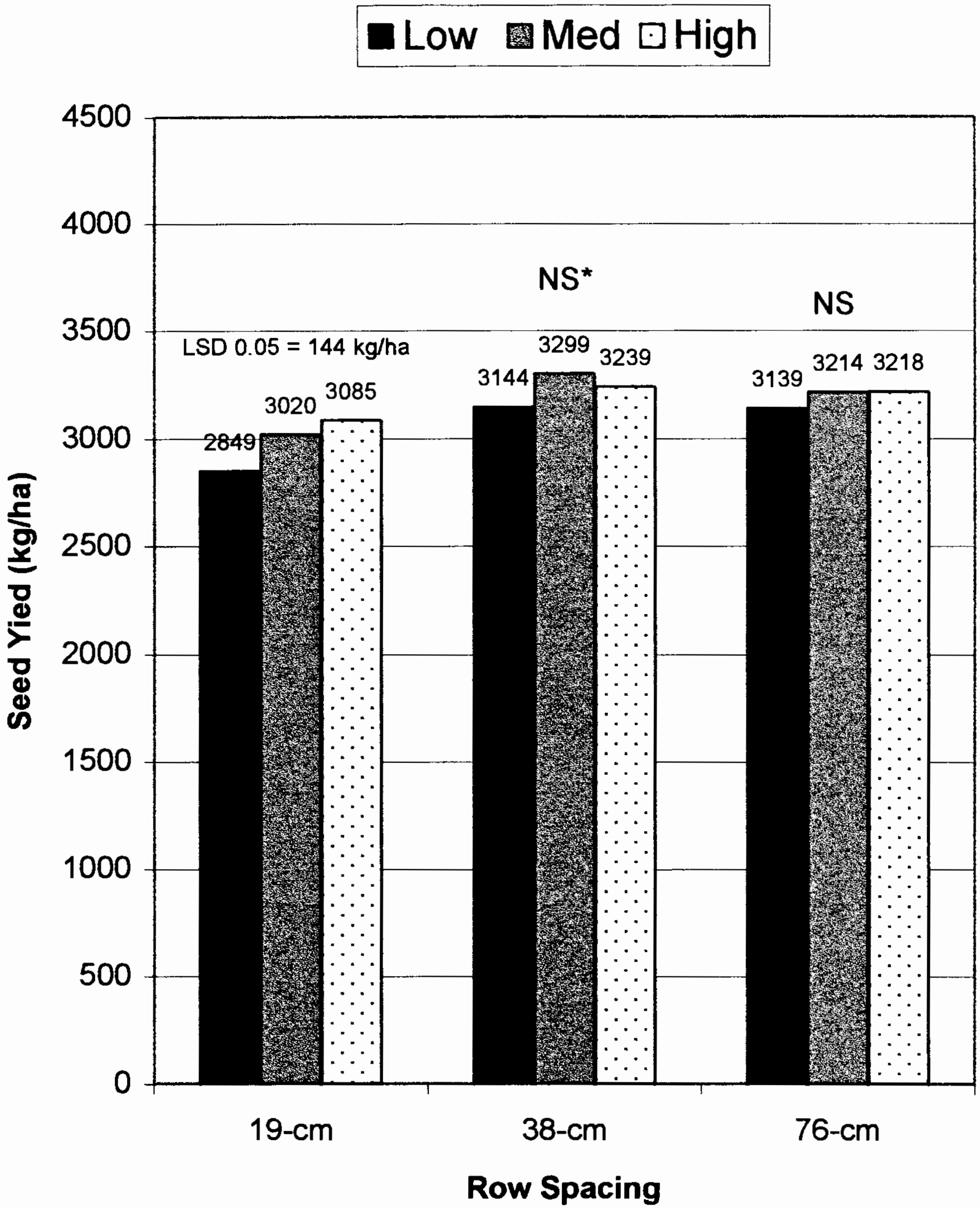


Figure 10. Planting date influence on soybean yield response to row spacing at the Ames location (1998).



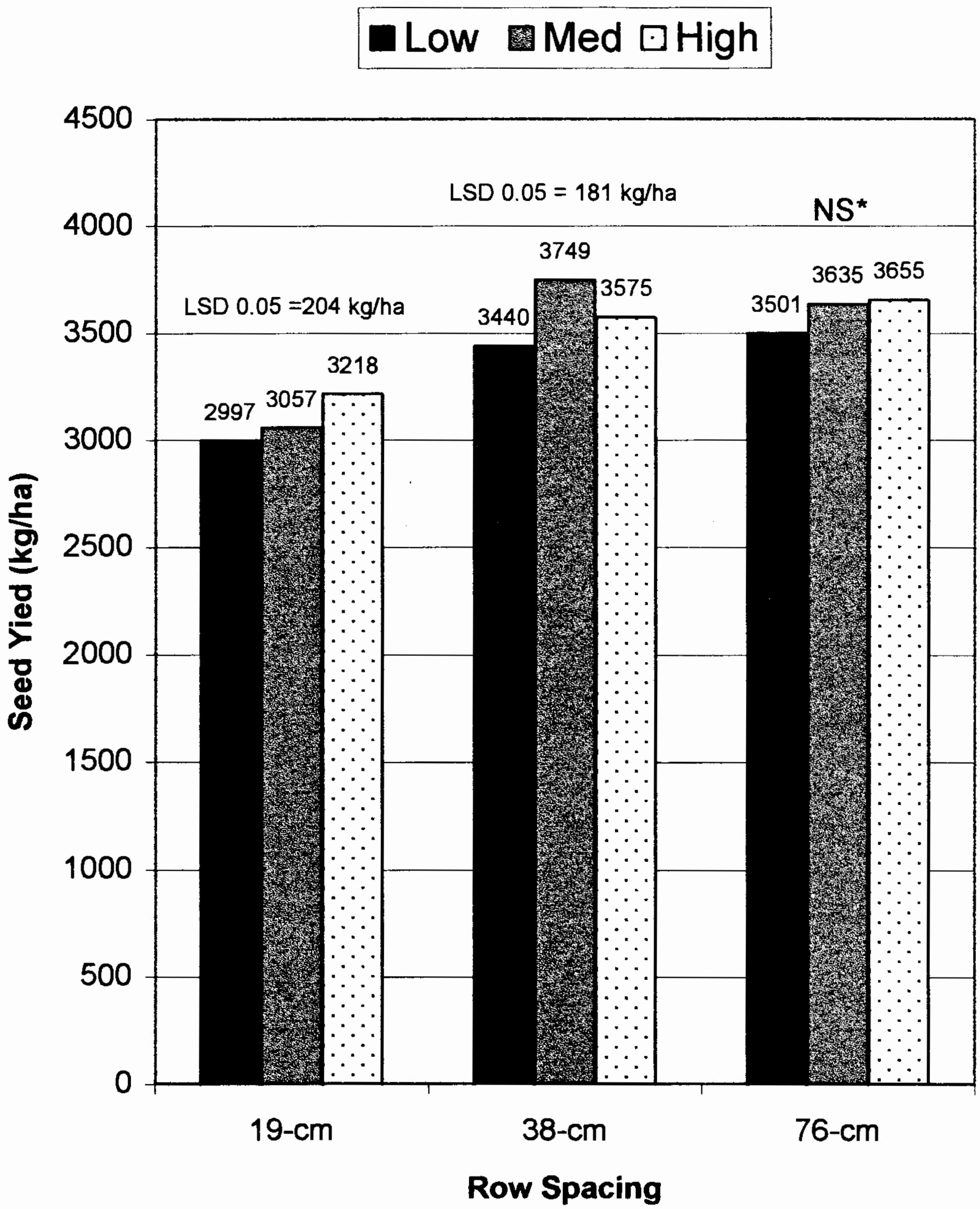
*Within a planting date, "NS" denotes no significant statisitcal differences at the (P=0.05) level.

Figure 11. Planting date influence on soybean yield response to row spacing at the Ames location (1999).



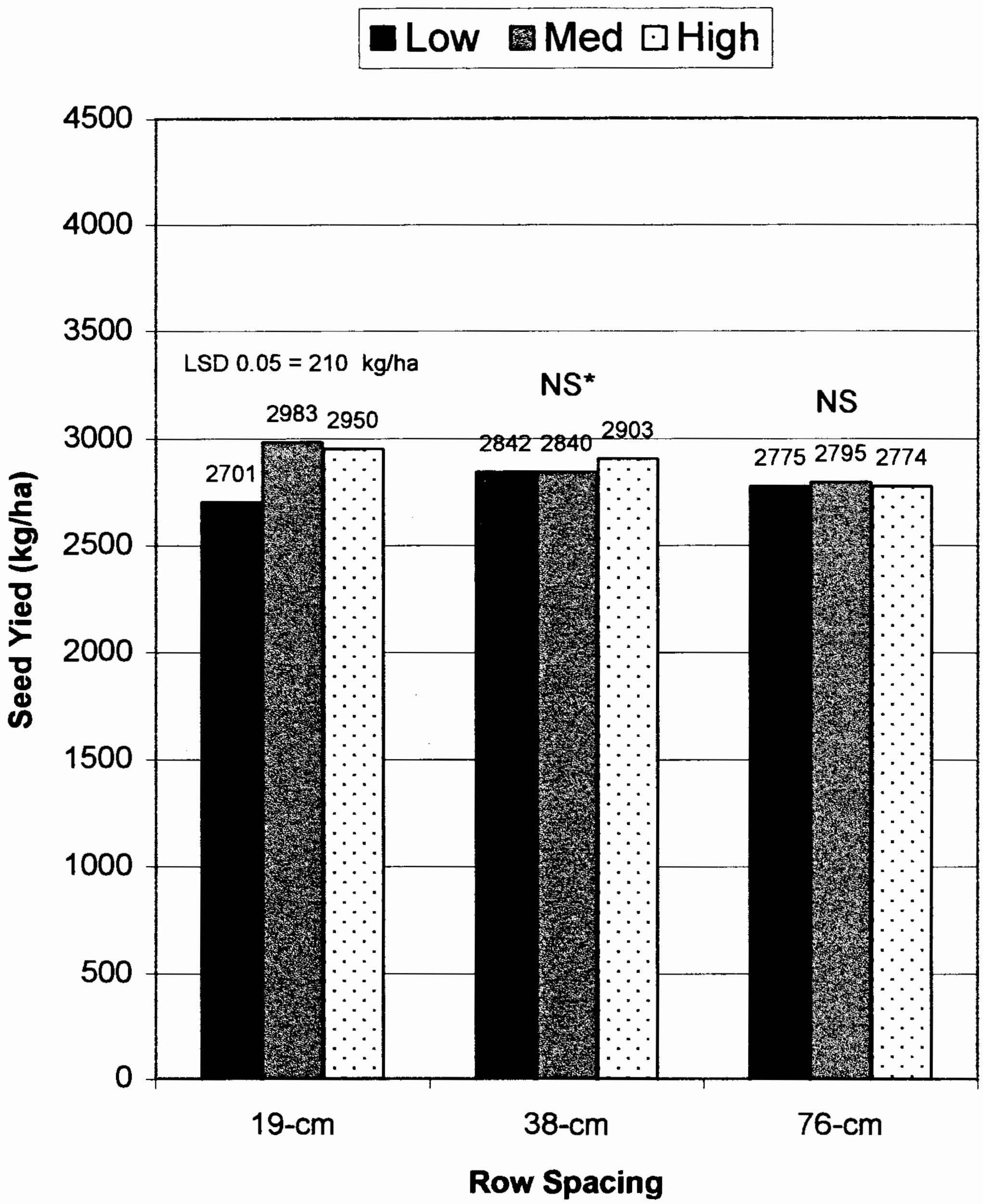
*Within a row spacing,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 12. Row spacing influence on soybean yield response to seeding rate at the Ames location (1998-1999).



*Within a row spacing,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 13. Row spacing influence on soybean yield response to seeding rate at the Ames location (1998).



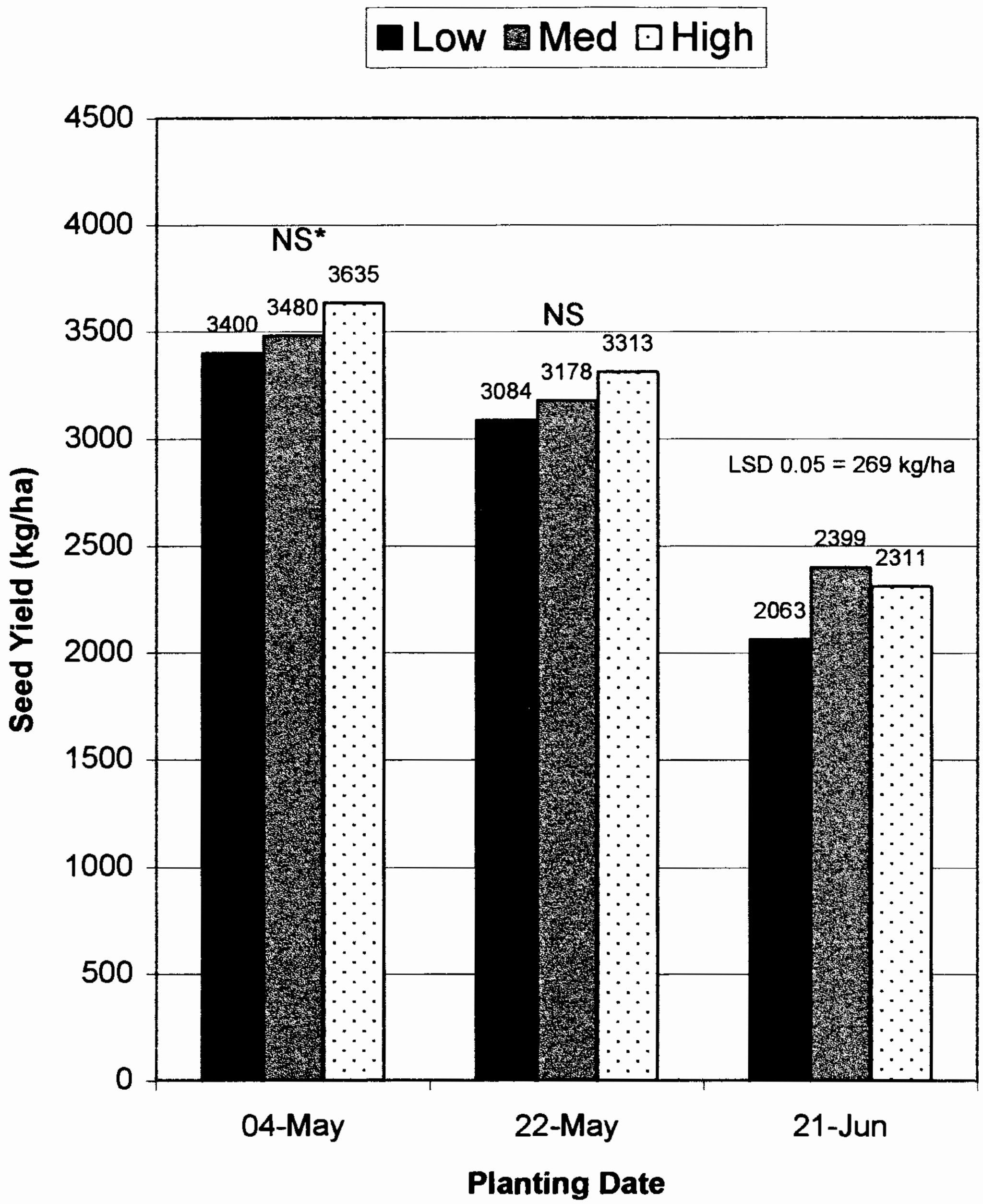
*Within a row spacing,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 14. Row spacing influence on soybean yield response to seeding rate at the Ames location (1999).

response to seeding rate in the 1998 season. There was no seeding rate influence on yield in the 76-cm rows. Soybeans planted in 19- and 38-cm rows, however, showed a yield response to seeding rate. Yield of soybeans planted in 19-cm rows increased as seeding rate increased. The increases from the low level to the medium and high levels produced higher yields. The yield increase was statistically significant when comparing the high and low seeding rate. The medium rate produced a yield average statistically similar to both the low and high rates. Soybeans planted in 38-cm rows responded to seeding rate in a similar manner, except highest yields were achieved at the medium seeding rate; high seeding rates produced yields statistically similar to both the low and medium rates. In 1998, row spacing influenced yield response to seeding rates, but the overall row spacing by seeding rate interaction was not statistically significant ($P = 0.19$). Figure 14 illustrates the 1999 season's row spacing influence on yield response to seeding rate. The 1999 individual season results were the same as the combined season data discussed above. In 1999, the row spacing by seeding rate interaction was not statistically significant ($P = 0.26$).

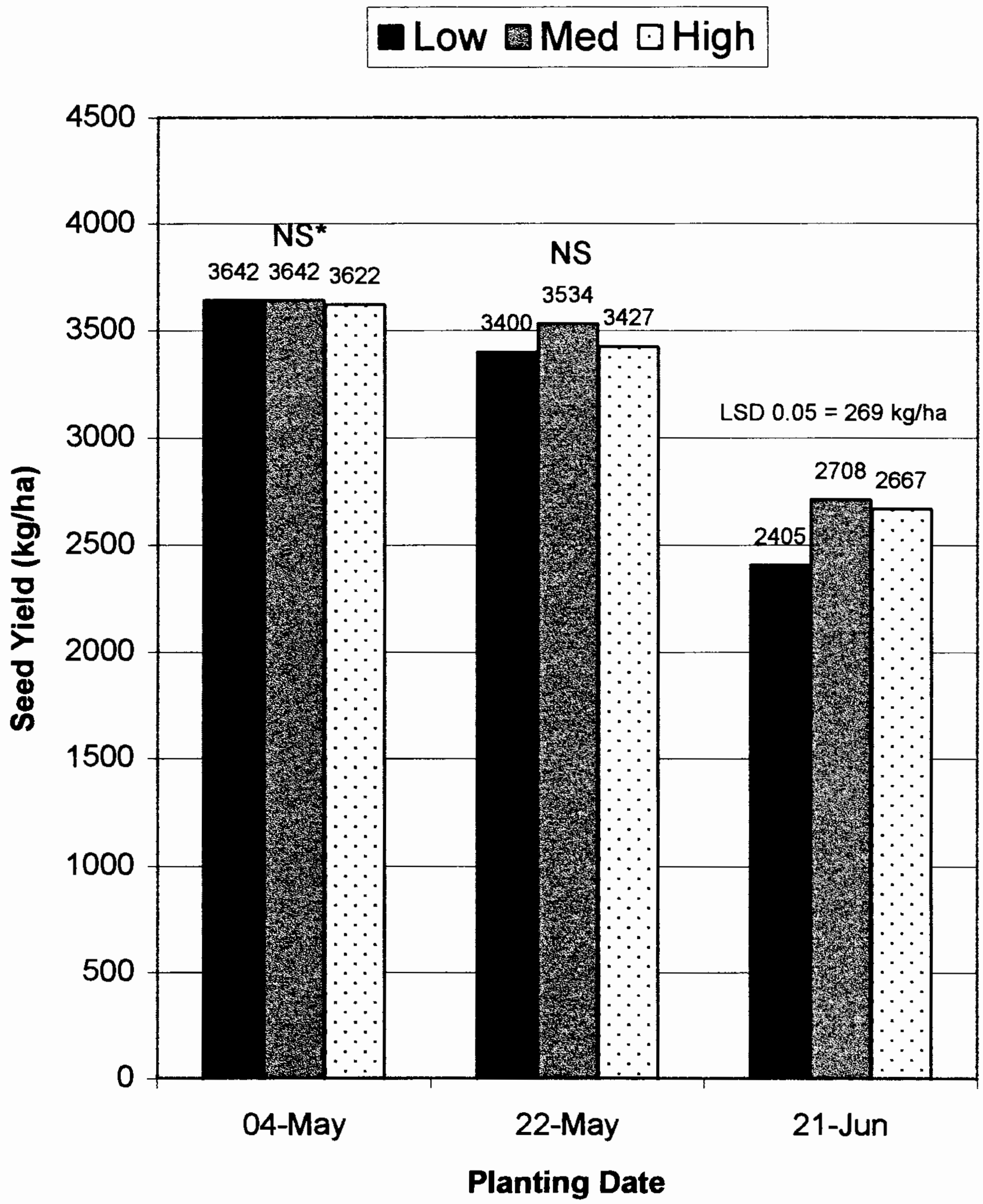
Figures 15-23 illustrate the combination of all three variables in this study. The planting date by row spacing by seeding rate interactions can be seen among these figures. Figures 15-17 illustrate the influence of planting date on yield response to seeding rate within a single row spacing for the combined season data. The row spacing by planting date influence on yield response to seeding rate can be seen by looking across these three figures. The combined seasons data illustrates that there was no significant ($P = 0.98$) planting date by row spacing by seeding rate interaction, hence the identical trends for all three figures.

Figures 18-20 illustrate the influence of planting date on yield response to plant population within a single row spacing for the 1998 season. Again row spacing by planting



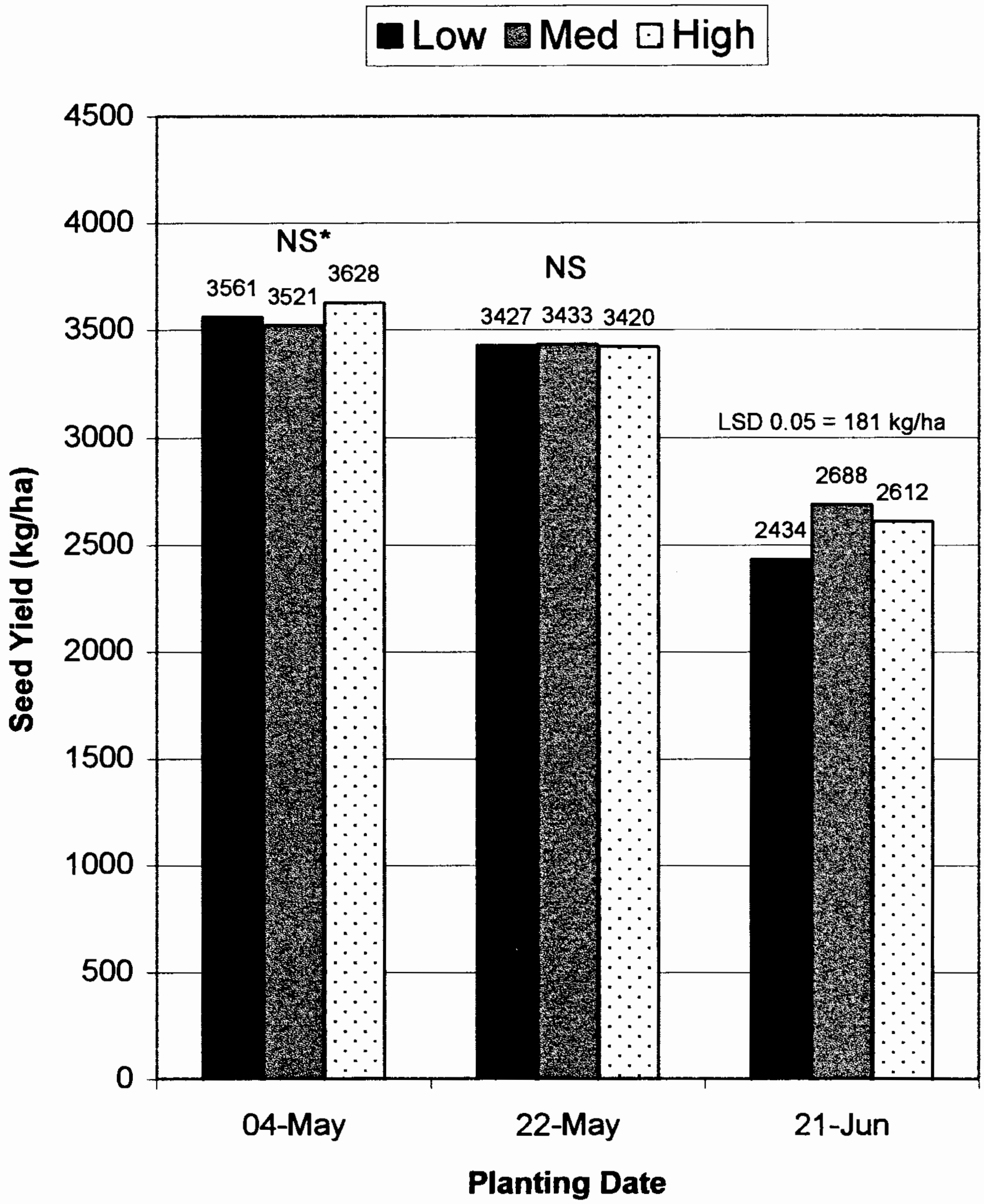
*Within a planting date,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 15. Planting date influence on soybean seed yield response to seeding rate in 19-cm rows at the Ames location (1998-1999).



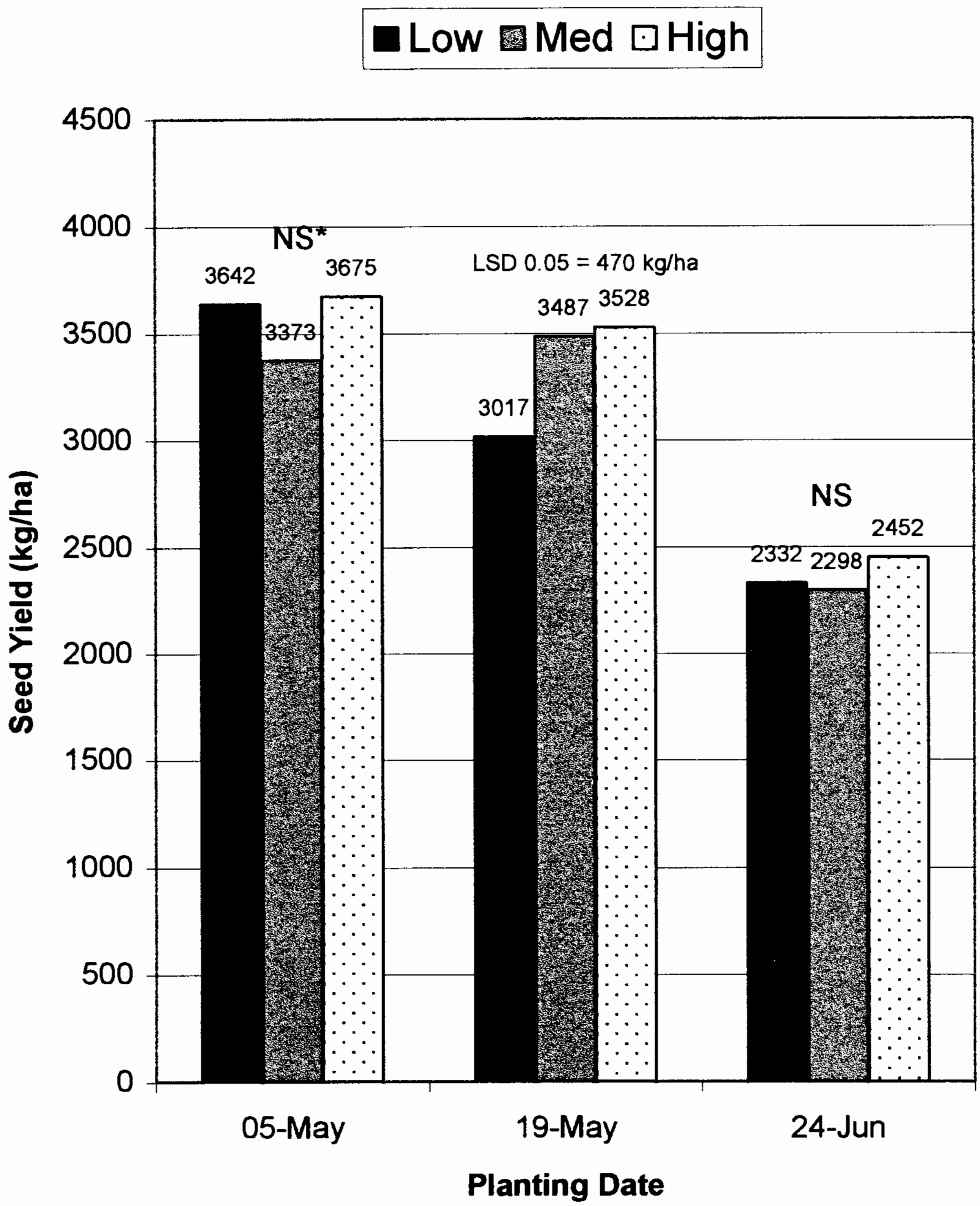
*Within a planting date, "NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 16. Planting date influence on soybean seed yield response to seeding rate in 38-cm rows at the Ames location (1998-1999).



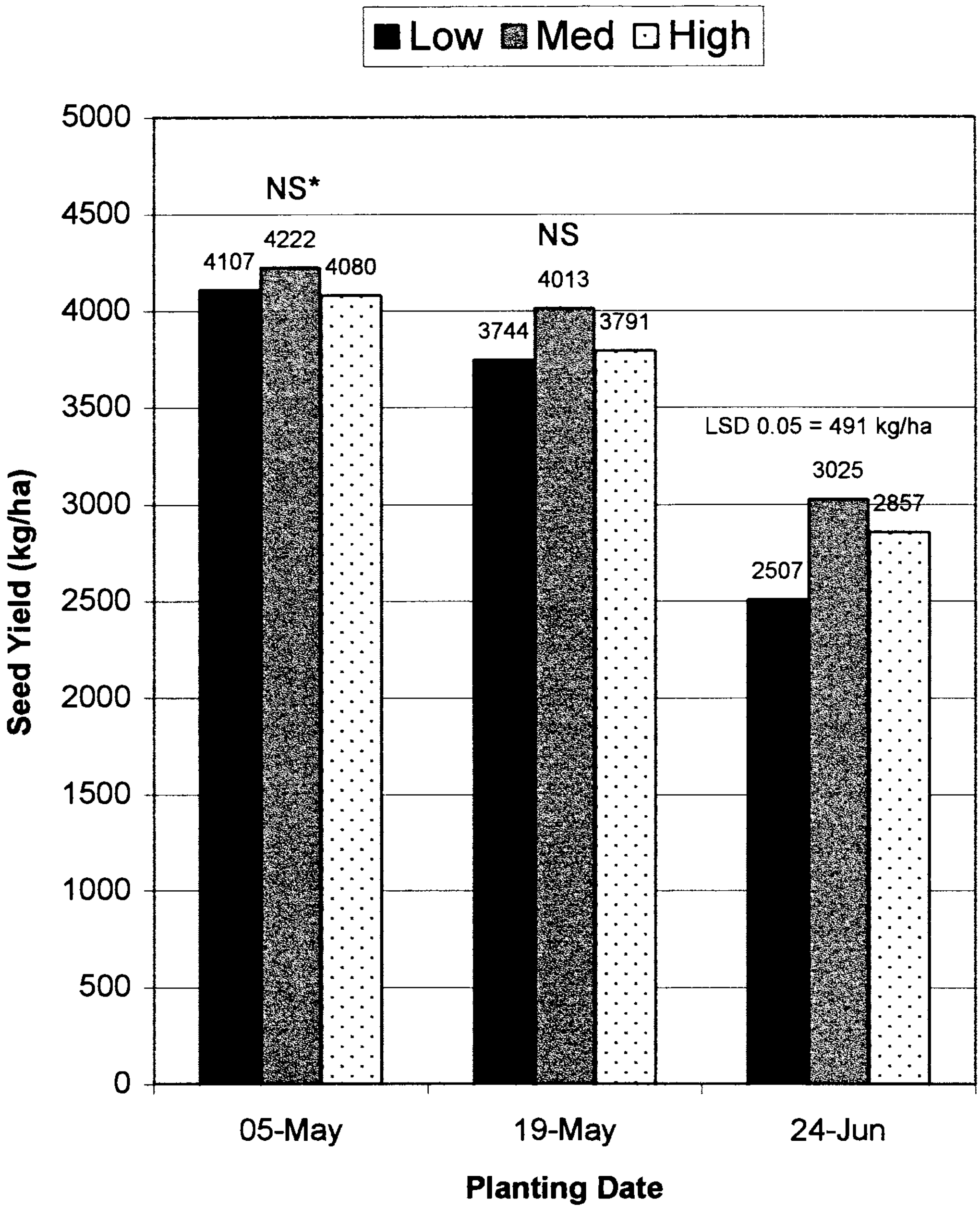
*Within a planting date,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 17. Planting date influence on soybean seed yield response to seeding rate in 76-cm rows at the Ames location (1998-1999).



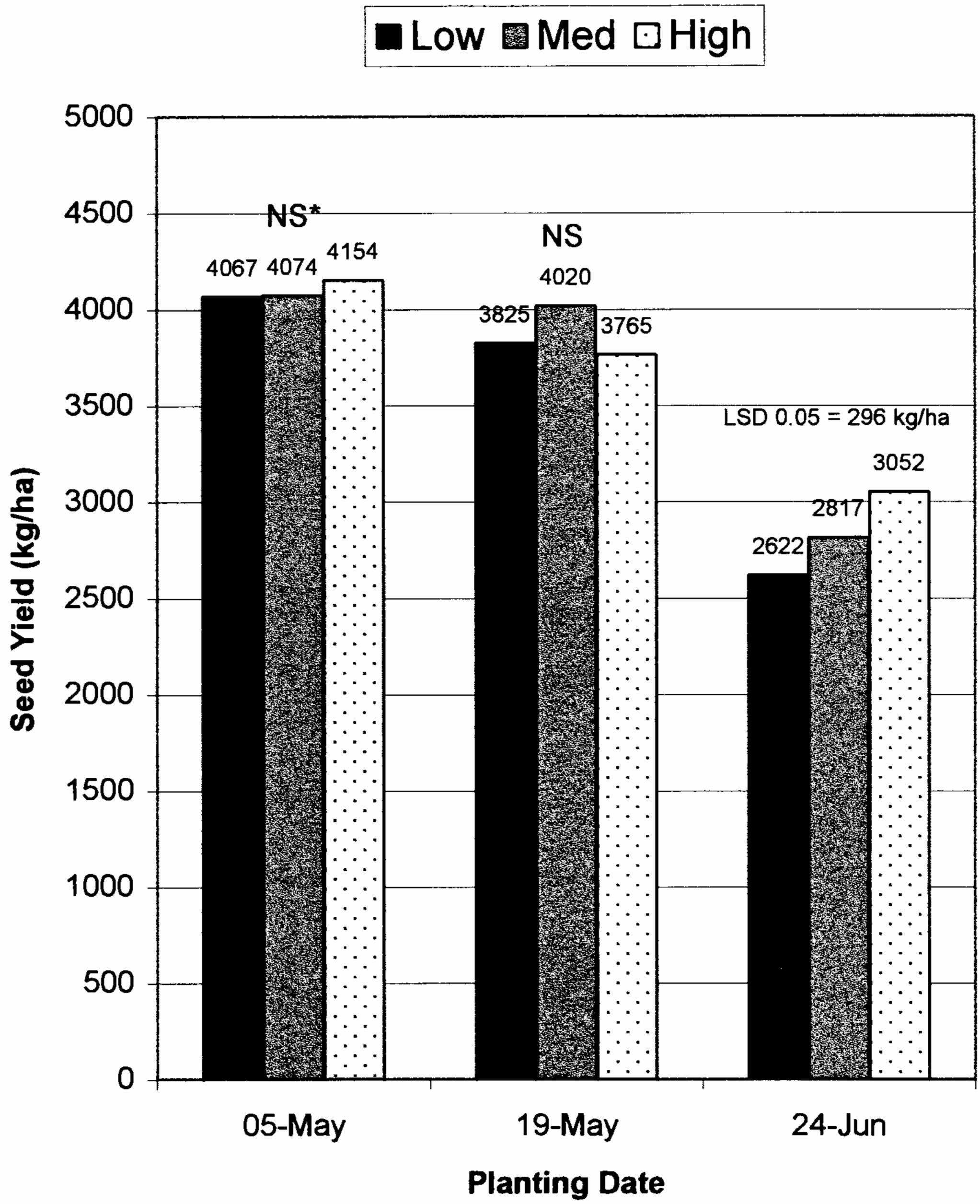
*Within a planting date, letters denote statistical significance at the (P=0.05) level.
**Within a planting date,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 18. Planting date influence on soybean seed yield response to seeding rate in 19-cm rows at the Ames location (1998).



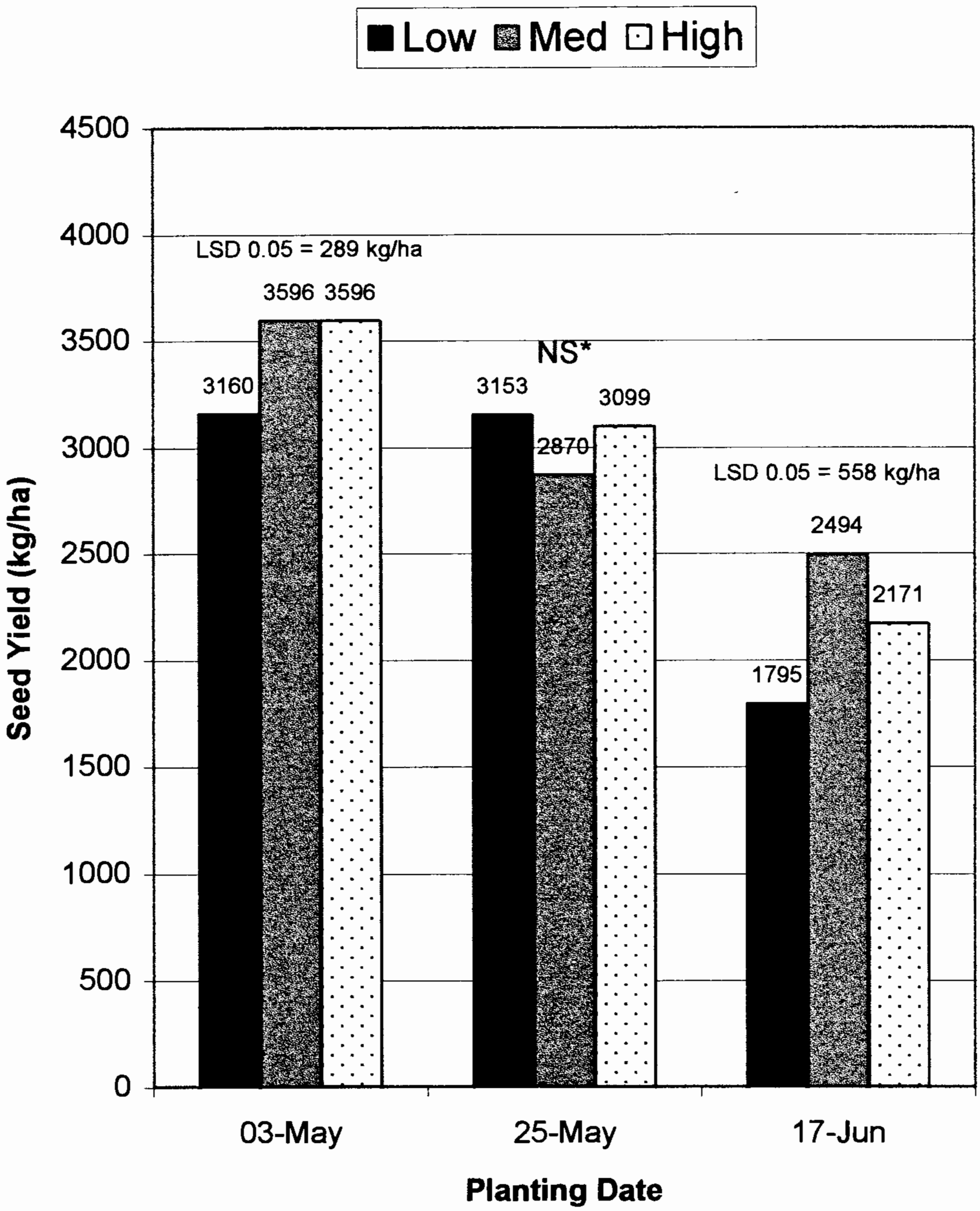
*Within a planting date,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 19. Planting date influence on soybean seed yield response to seeding rate in 38-cm rows at the Ames location (1998).



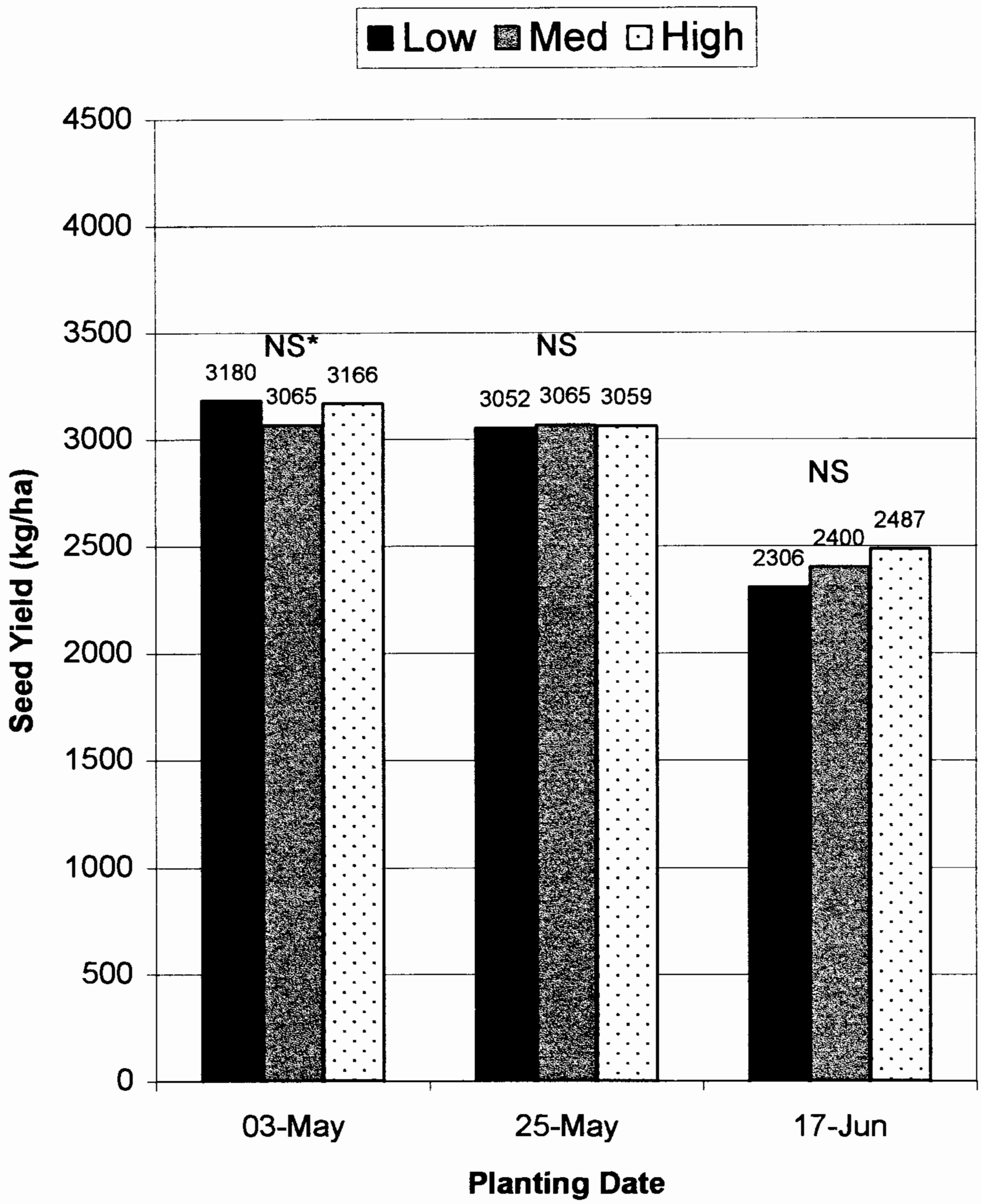
*Within a planting date,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 20. Planting date influence on soybean seed yield response to seeding rate in 76-cm rows at the Ames location (1998).



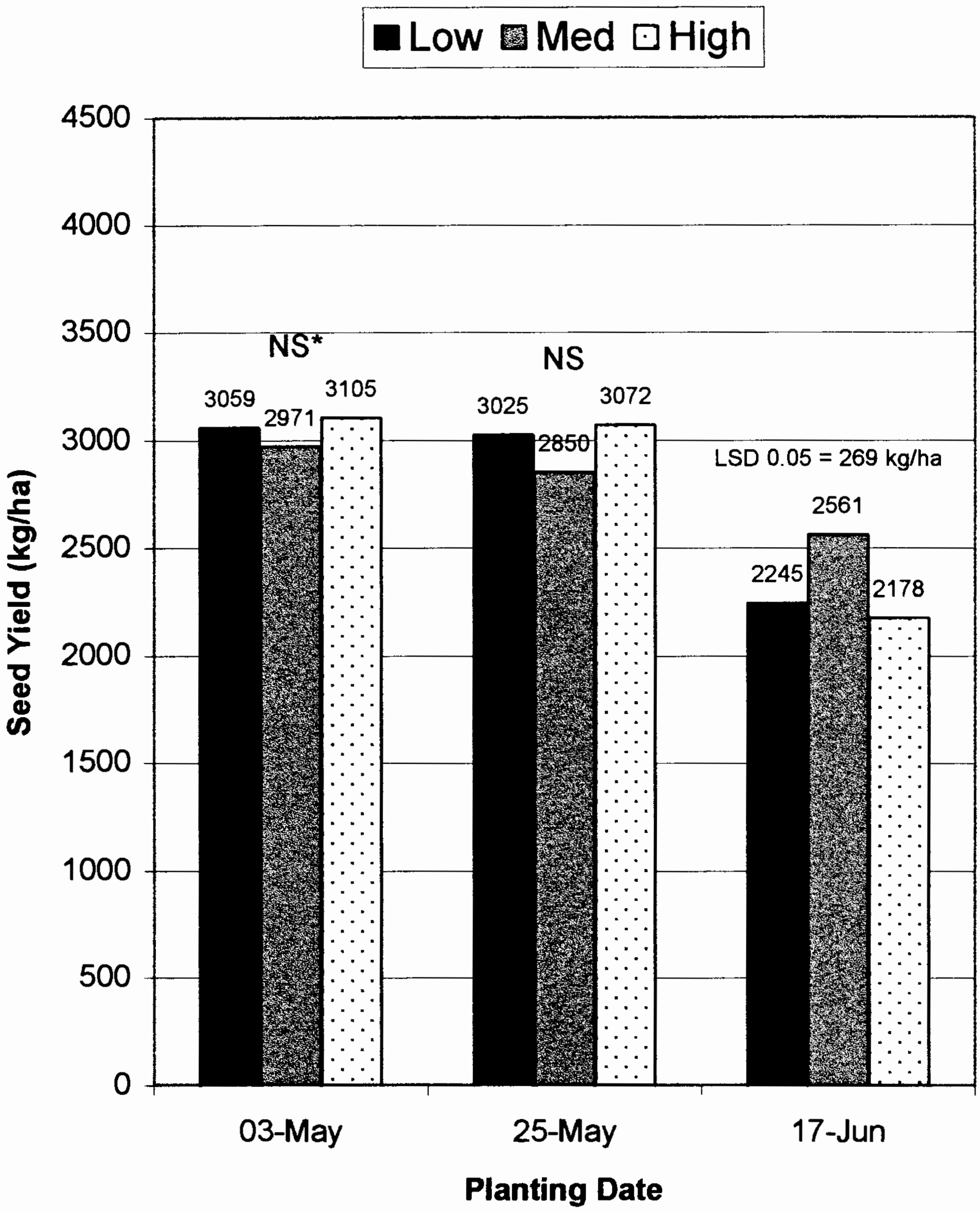
*Within a planting date,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 21. Planting date influence on soybean seed yield response to seeding rate in 19-cm rows at the Ames location (1999).



*Within a planting date, "NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 22. Planting date influence on soybean seed yield response to seeding rate in 38-cm rows at the Ames location (1999).



*Within a planting date,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 23. Planting date influence on soybean seed yield response to seeding rate in 76-cm rows at the Ames location (1999).

date influence on yield response to plant population can be seen by looking across the three figures. The single year shows a greater interaction ($P = 0.25$) between the three variables, however, the interaction is still not statistically significant. The 1999 data can be seen in Figures 21-23. The 1999 data is similar to that of the 1998 season. The charts indicate that both planting date and row spacing influence the yield response to plant population. The planting date by row spacing by plant population interaction ($P = 0.21$) was similar in 1999 to that observed in 1998, again indicating no statistically significant interaction.

Effects of planting date, row spacing, and plant population on soybean plant height and yield components

Soybean yields are a result of a combination of yield components. The number of pods per plant, seed number, and seed size/weight are three key components in soybean yield. Plant height also can be a key component in soybean seed yield. Plant height has a direct influence on lodging occurrence and severity. Plants that grow extremely tall will tend to lodge more increasing both harvest difficulty and seed yield losses. In this study, plant height, number of pods per plant, seeds per kilogram, 100-seed weight, and seeds per pod (1999 only) were evaluated. In many cases, treatments had significant influences on these yield components. Tables 2 and 3 provide treatment means for all of the yield components measured. Seeds-per-pod data are not presented due to a lack of response to treatments.

Average soybean plant height only varied by 2.5%, or 1.78-cm, between the two growing seasons; however, the analysis of variance indicated that the year effect on plant height was significant (Figure 24). Figure 25 shows the planting date effect on plant height. Planting date significantly affected the soybean plant height in each season as well as in the

Table 2. Mean plant heights and number of pods per plant for all treatments in Ames, 1998 and 1999.

Treatment	Mean Treatment Heights (cm) 1998	Mean Treatment Heights (cm) 1999	Mean # Pods Per Plant 1998	Mean # Pods Per Plant 1999
Date 1				
19-cm Low[1]	66[2]	71	68	60
19-cm Med	69	74	66	54
19-cm High	71	76	59	49
38-cm Low	69	69	54	61
38-cm Med	71	71	51	55
38-cm High	74	74	44	53
76-cm Low	66	69	49	62
76-cm Med	71	71	49	54
76-cm High	74	74	43	46
Date 2				
19-cm Low	76	81	60	49
19-cm Med	81	81	41	43
19-cm High	81	84	52	40
38-cm Low	79	79	56	52
38-cm Med	81	81	43	43
38-cm High	84	84	41	42
76-cm Low	79	79	51	48
76-cm Med	79	81	48	40
76-cm High	81	81	40	30
Date 3				
19-cm Low	53	56	66	48
19-cm Med	56	58	45	34
19-cm High	56	61	41	31
38-cm Low	53	56	49	44
38-cm Med	58	61	45	41
38-cm High	61	61	43	35
76-cm Low	56	58	60	35
76-cm Med	58	61	42	29
76-cm High	61	64	34	27

[1]Seeding rates were 296,400 plants/ha (Low), 395,200 plants/ha (Med), and 494,000 plants/ha (High).
[2]Heights were measured from the soil surface to the terminal pod of the top node on the main stem at physiological maturity (R8).

Table 3. Mean Seeds/kg and 100-Seed weight for all treatments in Ames, 1998 and 1999.

Treatment	Mean # Seeds/kg		100-Seed Weight (g)	
Date 1	1998	1999	1998	1999
19-cm Low[1]	1398	1541	15.69	13.27
19-cm Med	1387	1512	15.72	14.26
19-cm High	1397	1519	15.40	14.12
38-cm Low	1392	1560	15.64	14.39
38-cm Med	1367	1552	15.82	14.60
38-cm High	1381	1564	16.21	14.38
76-cm Low	1371	1545	14.67	13.11
76-cm Med	1327	1531	14.44	13.96
76-cm High	1309	1552	14.58	14.09
Date 2				
19-cm Low	1386	1456	15.59	13.76
19-cm Med	1379	1475	15.84	13.77
19-cm High	1387	1500	15.47	13.83
38-cm Low	1411	1505	14.77	14.18
38-cm Med	1359	1481	15.25	14.02
38-cm High	1402	1528	14.96	14.36
76-cm Low	1375	1560	14.56	13.11
76-cm Med	1367	1443	14.44	12.86
76-cm High	1372	1507	14.72	13.36
Date 3				
19-cm Low	1438	1606	15.66	14.35
19-cm Med	1460	1570	16.12	13.84
19-cm High	1431	1493	16.05	13.85
38-cm Low	1450	1643	15.43	13.83
38-cm Med	1442	1614	15.41	14.36
38-cm High	1429	1578	15.17	14.41
76-cm Low	1413	1594	15.39	13.61
76-cm Med	1406	1615	15.46	13.86
76-cm High	1381	1604	15.49	13.43

[1]Seeding rates were 296,400 plants/ha (Low), 395,200 plants/ha (Med), and 494,000 plants/ha (High). Actual harvest stands are shown in Table 1.

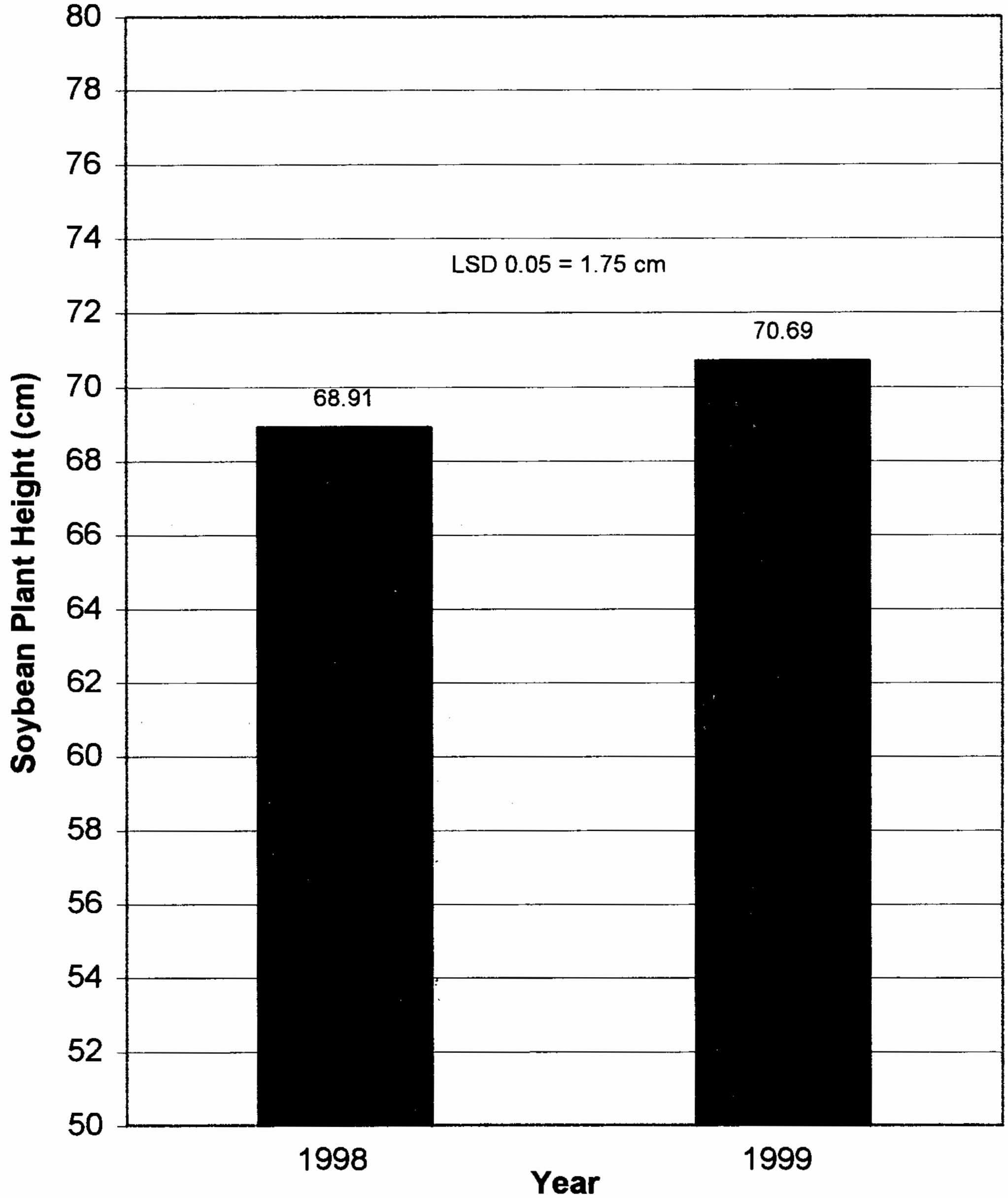


Figure 24. Average soybean plant height at the Ames location (1998 and 1999).

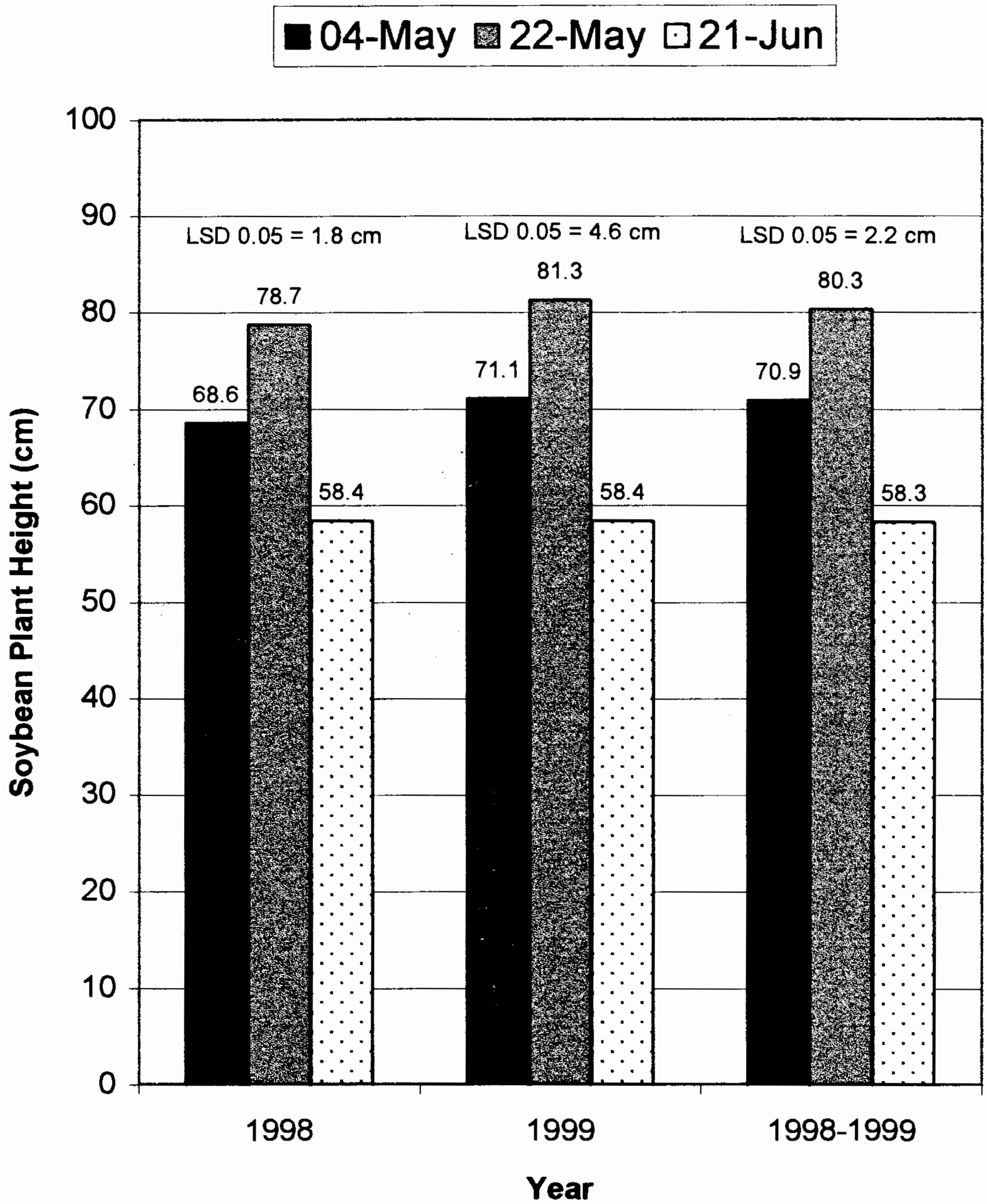
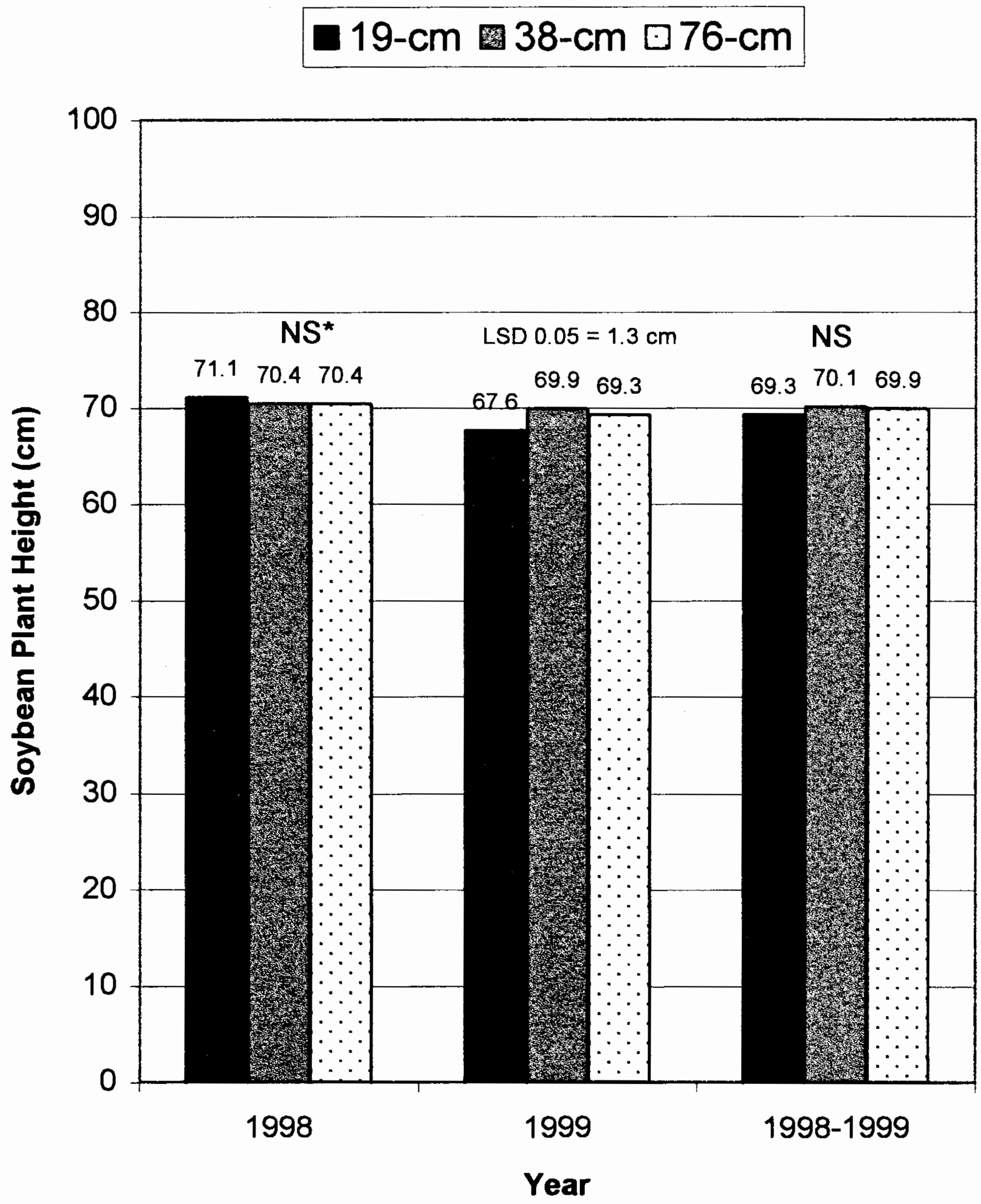


Figure 25. Planting date effect on soybean plant height at the Ames location (1998, 1999, and 1998-1999).

combined data. Past studies have indicated that soybean plant height is reduced with later season planting, mostly due to the reduced amount of time for vegetative growth (Beaver and Johnson, 1981; Beatty et al., 1982). In this study planting date influence on plant height was the same in each season and in the combined seasons. The tallest plants were produced on the second planting date. Soybeans planted on the second date, were on average, 9.9 cm taller than those planted on the first planting date and 21.7 cm taller than those planted on the third planting date. Both differences in plant height were statistically significant. The significant difference in plant height observed between Dates One and Two most likely was caused by cool, wet weather conditions in early May and agrees with findings by Anderson and Vasilas (1985).

Plant height was not significantly affected by row spacing (Figure 26). The combined season data and the 1998 data revealed no soybean plant height differences among the three row spacings. In 1999, soybeans planted in 19-cm rows were significantly shorter than those planted in 38- and 76-cm rows, with no significant differences between soybeans planted in 38- and 76-cm rows. Past studies have indicated very inconsistent row spacing effects on plant height. Several studies have shown a decrease in plant height with a reduction in row spacing (Sesay, 1972; Taylor, 1980). Other reports have shown an increase in plant height when row spacing was reduced (Beaver and Johnson, 1981; Bharati, 1984). The inconsistency of these results suggests that plant height may be more greatly influenced by other factors such as planting date and plant population (Wykle, 1997).

Seeding rate influenced plant height in each season and in the combined data. Figure 27 shows that the seeding rate influence on plant height was very similar in each season. Plant height increased significantly with each increase in seeding rate. This response has



*NS denotes no significant statistical difference at the (P=0.05) level.

Figure 26. Row spacing effects on soybean plant height at the Ames location (1998 1999, and 1998-1999).

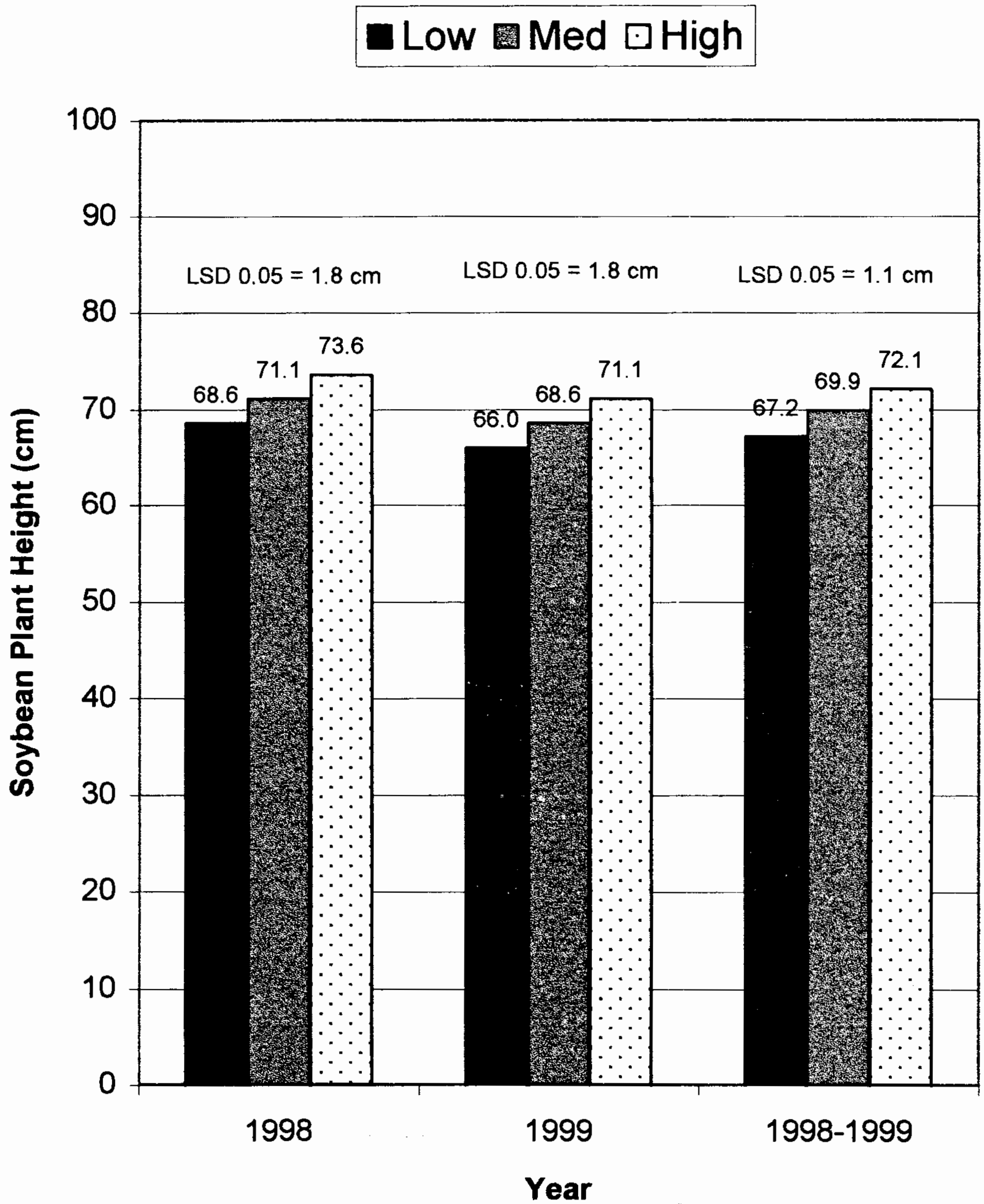


Figure 27. Seeding rate effects on soybean plant height at the Ames location (1998,1999, and 1998-1999).

been well documented (Cooper, 1971b; Wykle, 1997; Tranel, 1999). Generally, taller plants are associated with increased plant populations because of a higher level of plant competition (Alessi and Power, 1982).

Pod production also differed significantly in the two seasons (Figure 28). This difference may be attributed to the dry conditions experienced during the pod production stages (R2.5-R6) in 1999. Figure 29 shows the planting date influence on pod production. In each season and the combined data, pod production tended to decline as planting date was delayed. The decline in pod production was not significant in the 1998 season; however, in 1999 and in the combined data, the decline observed from the first to the second planting was significant. Large decreases in pod production associated with planting delays may have been the key component contributing to lower yields.

Figure 30 illustrates the row spacing influence on pod production for each season and the combined season data. The trend is similar in each year, indicating a significant pod production increase in 19-cm rows relative to 76-cm rows. The 1998 and combined seasons data also indicates that the plants in 19-cm produced statistically more pods than those in 38-cm rows. Several researchers have reported that soybeans compensate for increased space between plants by increasing pod number (Enyi, 1973; Lueschen and Hicks, 1977).

Figure 31 provides additional evidence that soybeans compensate for increased space between plants and rows by producing more pods per plant. The seeding rate effects on pod production support this trend for each season and in the combined data. When seeding rate was increased there was a 10-15% decline in pod production. This decline was significant at each level in the 1999 and combined season data. In 1998, the increase from the medium to the high seeding rate produced statistically similar yields.

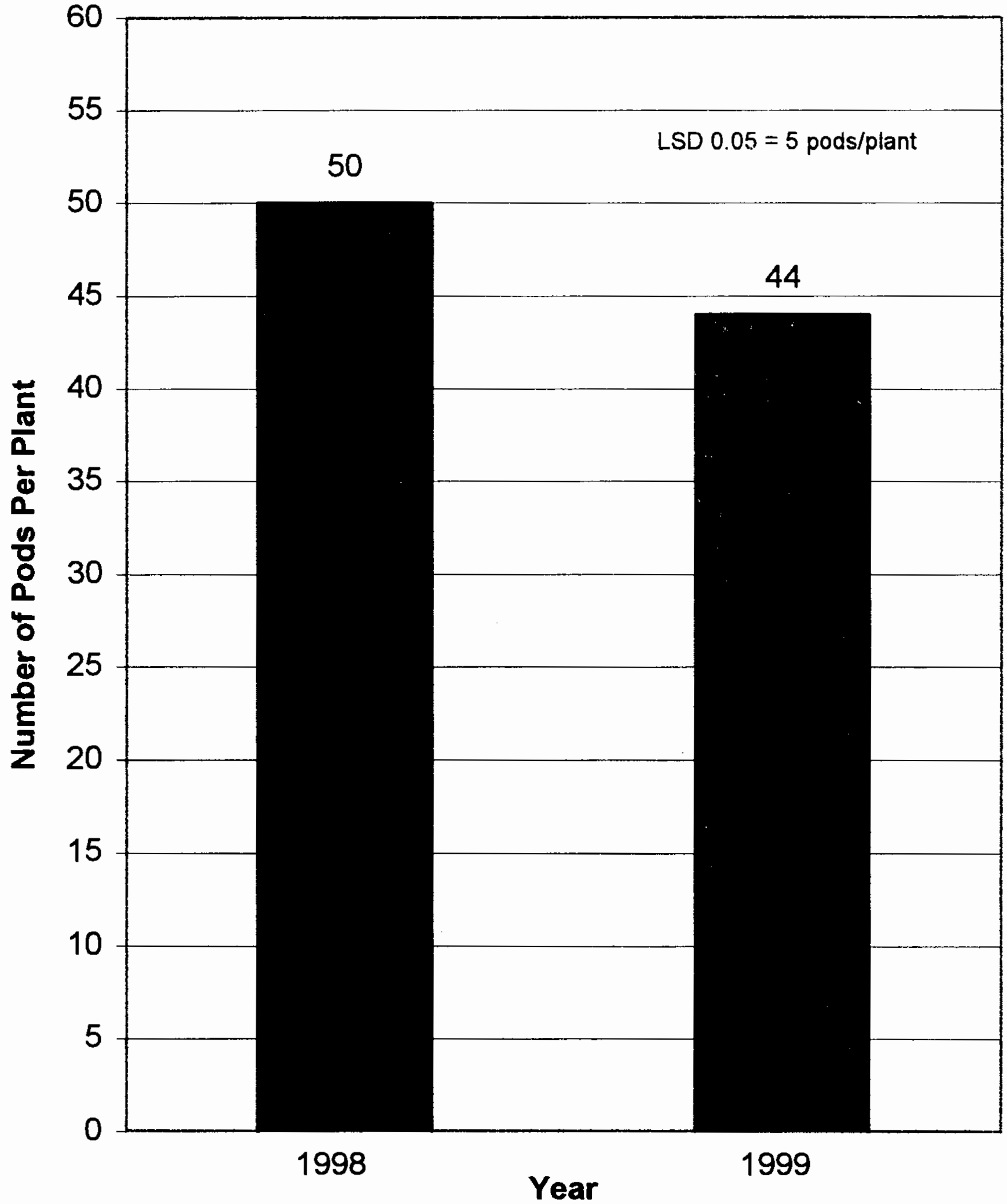
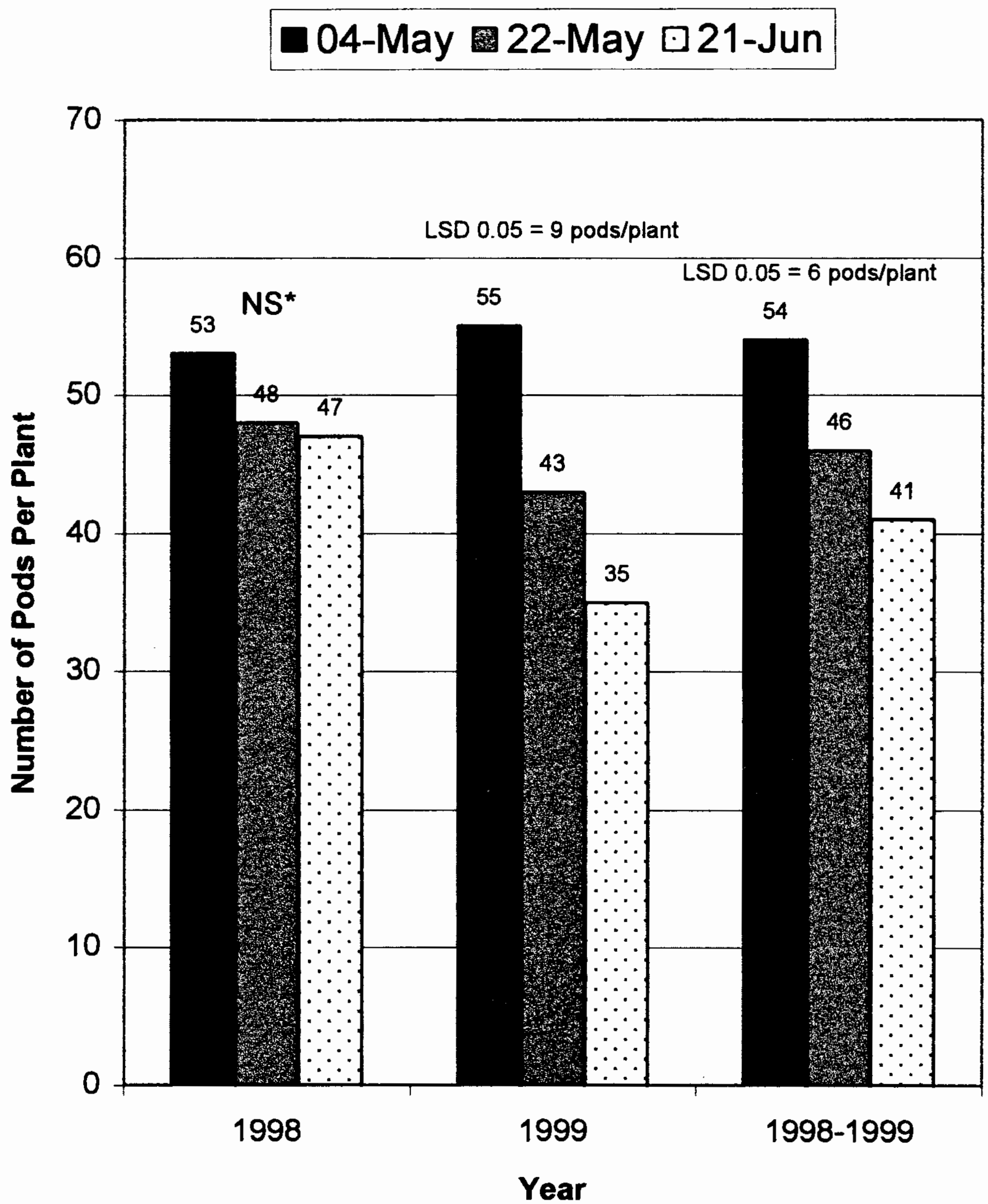


Figure 28. Average number of pods per plant at the Ames location (1998 and 1999).



*NS denotes no significant statistical difference at the (P=0.05) level.

Figure 29. Planting date effect on number of pods per plant at the Ames location (1998, 1999, and 1998-1999).

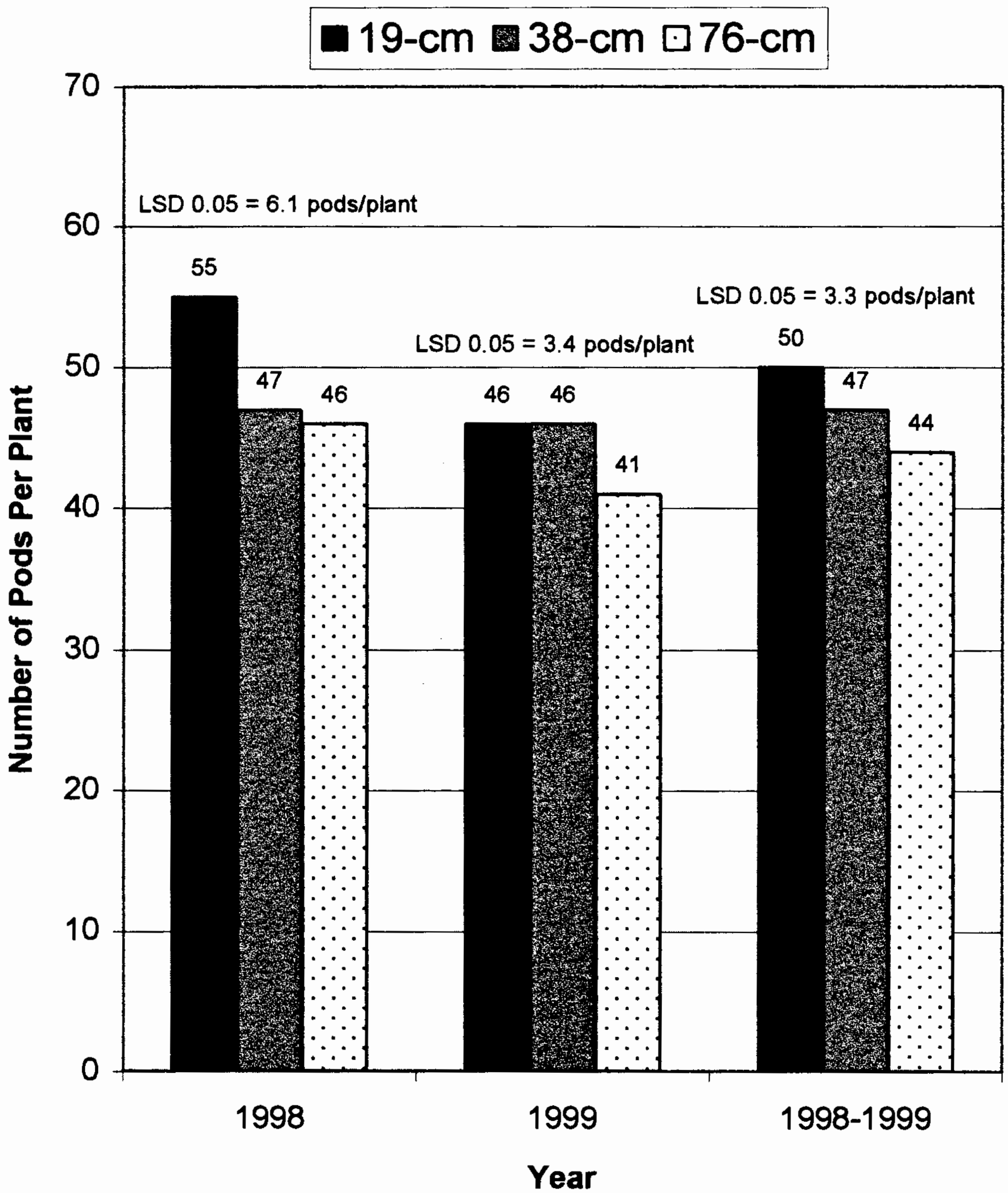


Figure 30. Row spacing effect on number of pods per plant at the Ames location (1998, 1999,and 1998-1999).

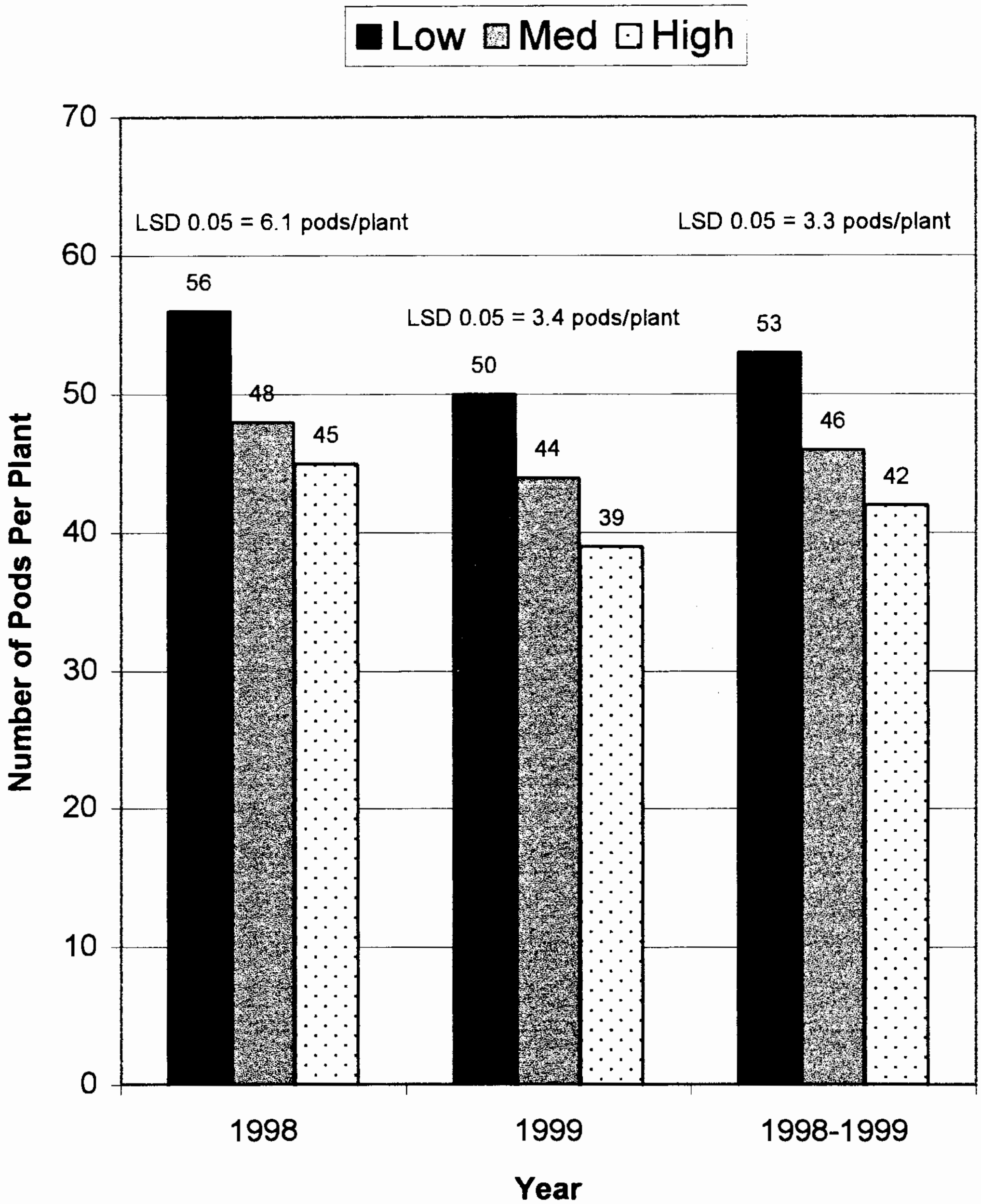


Figure 31. Seeding rate effect on number of pods per plant at the Ames location (1998, 1999,and 1998-1999).

Seeds per kilogram differed significantly by year (Figure 32), probably a result of stressful growing conditions during the critical seed filling stages (R4-R7) in 1999. Number of seeds per kilogram were increased by 10% in 1999, indicating a smaller average seed size than what was produced in 1998. Figure 33 illustrates the influence of planting date on seeds per kilogram. The trend varied slightly between years, but generally seed size decreased with planting delays. In each season, the third planting date produced the highest number of seeds per kilogram, suggesting that seed size was significantly reduced at the later planting date.

Figures 34 and 35 indicate the influence of row spacing and seeding rate on number of seeds per kilogram. The two charts indicate that as between-plant spacing increased, either by lower plant populations or narrower row spacings, the number of seeds per kilogram increased (seed size decreased). Past studies have indicated that soybeans planted in wide rows have fewer pods per plant than those grown in narrow rows, but compensate by increasing seed size (Reiss and Sherwood, 1965).

The 100-seed weight also was significantly lower in 1999 than in 1998, suggesting that stressful growing conditions during seed fill restricted seed size potential (Figure 36). The 100-seed weight average was 10% less in the 1999 season than in the 1998 season. Planting date influenced the 100-seed weight differently in 1998, 1999, and in the combined season data (Figure 37). In 1998, 100-seed weight declined significantly with each delay in planting date. In 1999, 100-seed weight response to planting date was less consistent. Largest seeds were associated with the middle planting date, although early and middle planting dates were statistically similar. Seed from late-planted soybeans was significantly smaller than those planted on the middle date; however, early and late-planted soybeans

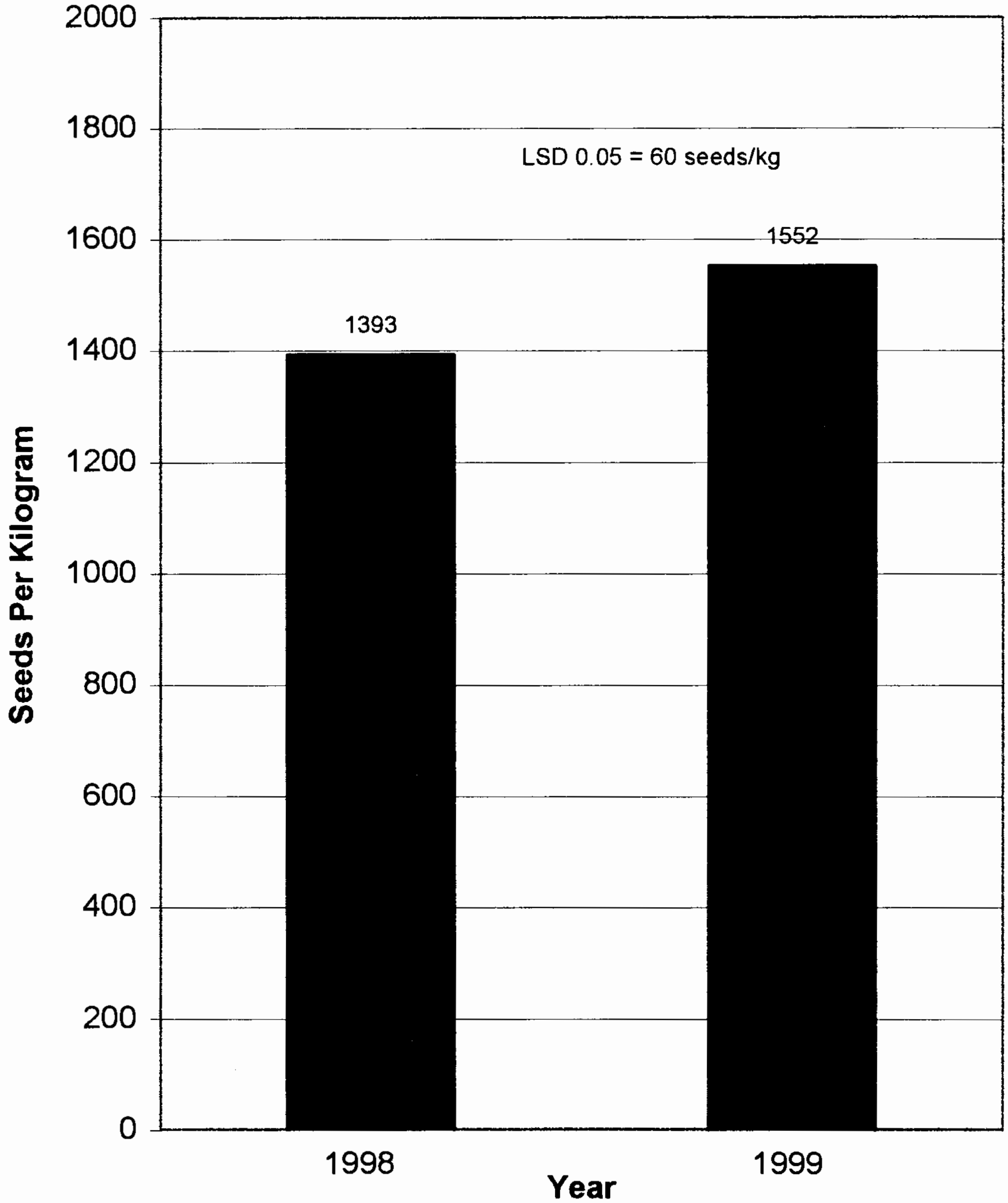


Figure 32. Average number of seeds per kilogram at the Ames location (1998 and 1999).

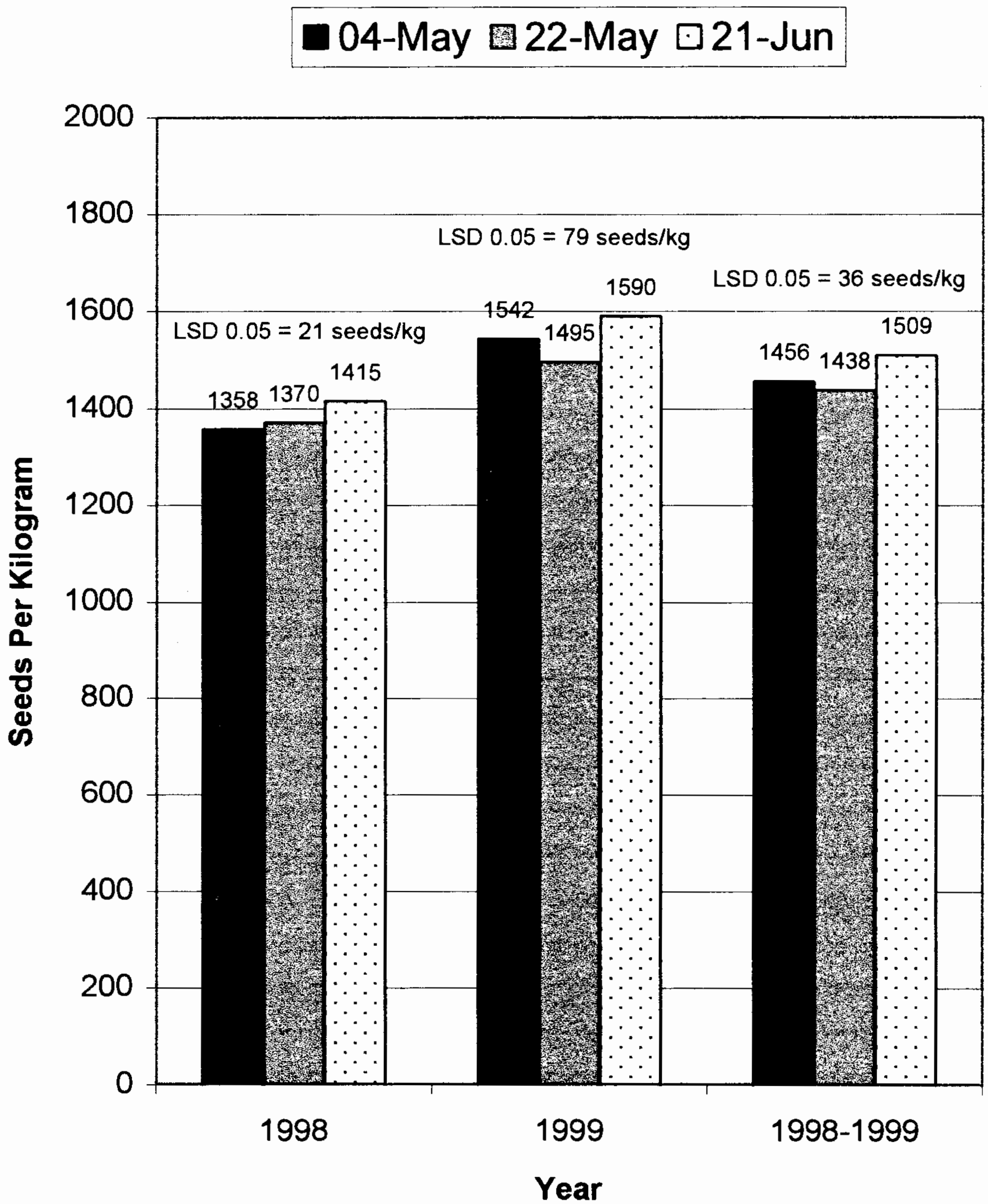


Figure 33. Planting date effect on number of seeds per kilogram at the Ames location (1998, 1999, and 1998-1999).

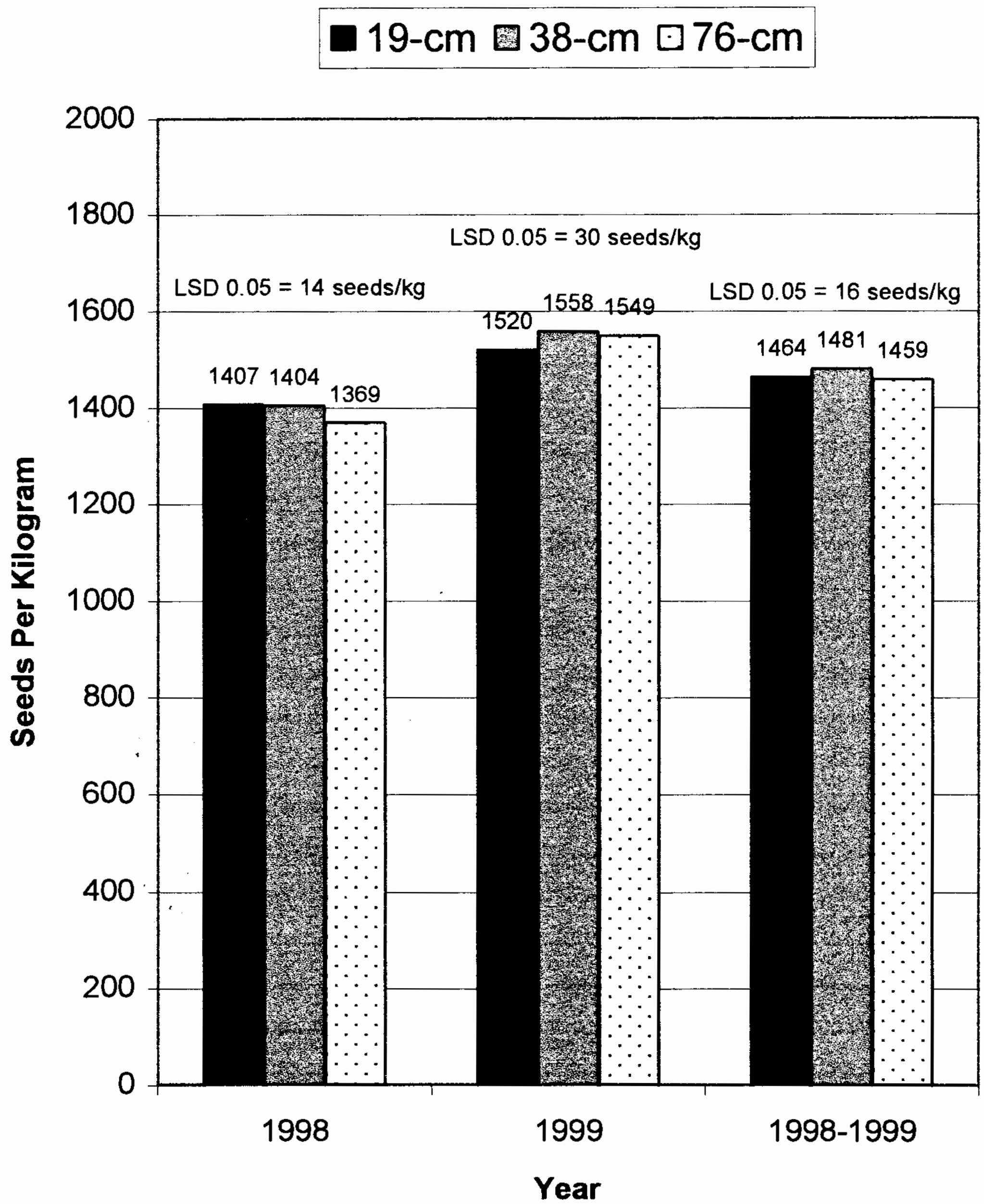
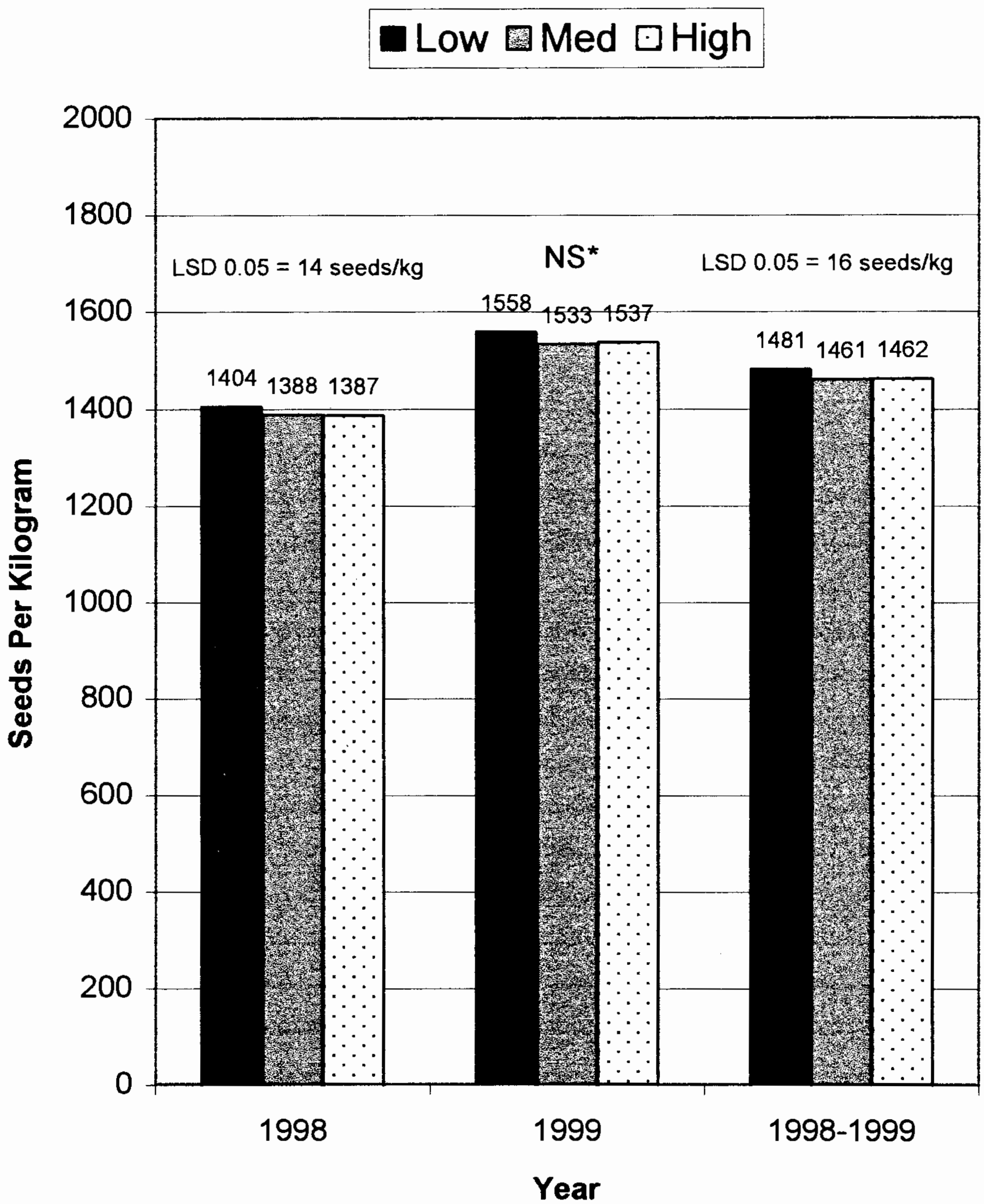


Figure 34. Row spacing effect on number of seeds per kilogram at the Ames location (1998, 1999, and 1998-1999).



*NS denotes no significant statistical difference at the (P=0.05) level.

Figure 35. Seeding rate effect on number of seeds per kilogram at the Ames location (1998, 1999, and 1998-1999).

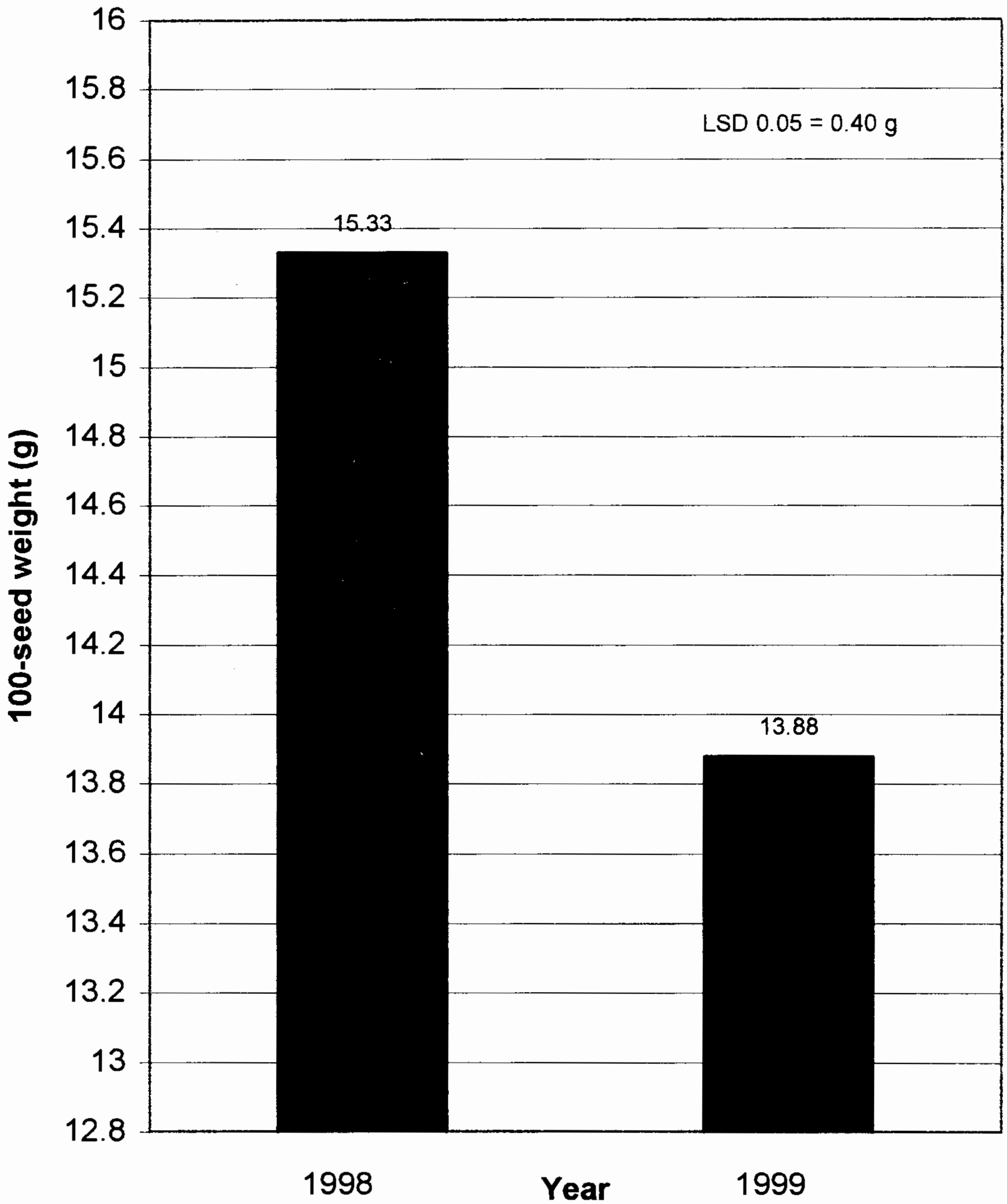


Figure 36. Average 100-seed weight at the Ames location (1998 and 1999).

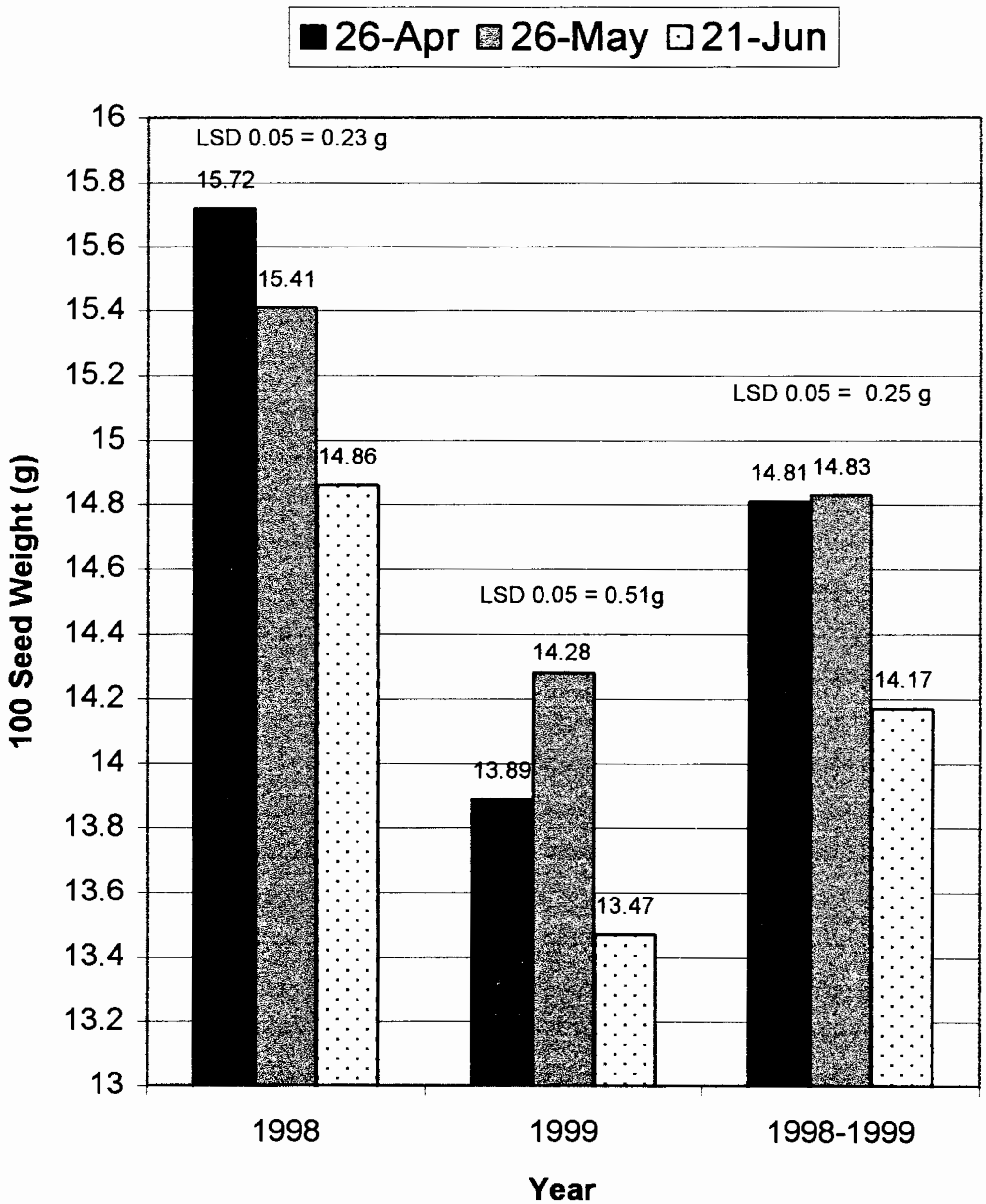


Figure 37. Planting date effect on 100-seed weight at the Ames location (1998, 1999, and 1998-1999).

produced seed of similar size. Over both years, 100-seed weights were similar for the first two planting dates and significantly higher than late-planted soybeans.

Figure 38 illustrates the row spacing effect on 100-seed weight. Within years, row spacings produced similar effects on 100-seed weight. For each season, soybeans planted in 19- and 76-cm rows produced largest seeds (highest 100-seed weights). These two row spacings produced statistically similar yields, however, the 38-cm spacing produced smaller seeds (reduced 100-seed weights) in each season and across seasons.

Figure 39 illustrates the seeding rate effect on 100-seed weight. In 1998, 100-seed weight was not affected by seeding rate. In 1999, there was a statistically significant increase in 100-seed weight when seeding rate increased from the low level to the medium level; however, a further increase in seeding rate did not affect 100-seed weight. Over two years, the highest 100-seed weight was associated with the medium seeding rate, with the high seeding rate producing significantly smaller seeds (reduced 100-seed weight) than the medium seeding rate. Soybeans planted at the low seeding rate produced 100-seed weights statistically similar to both medium and high seeding rates.

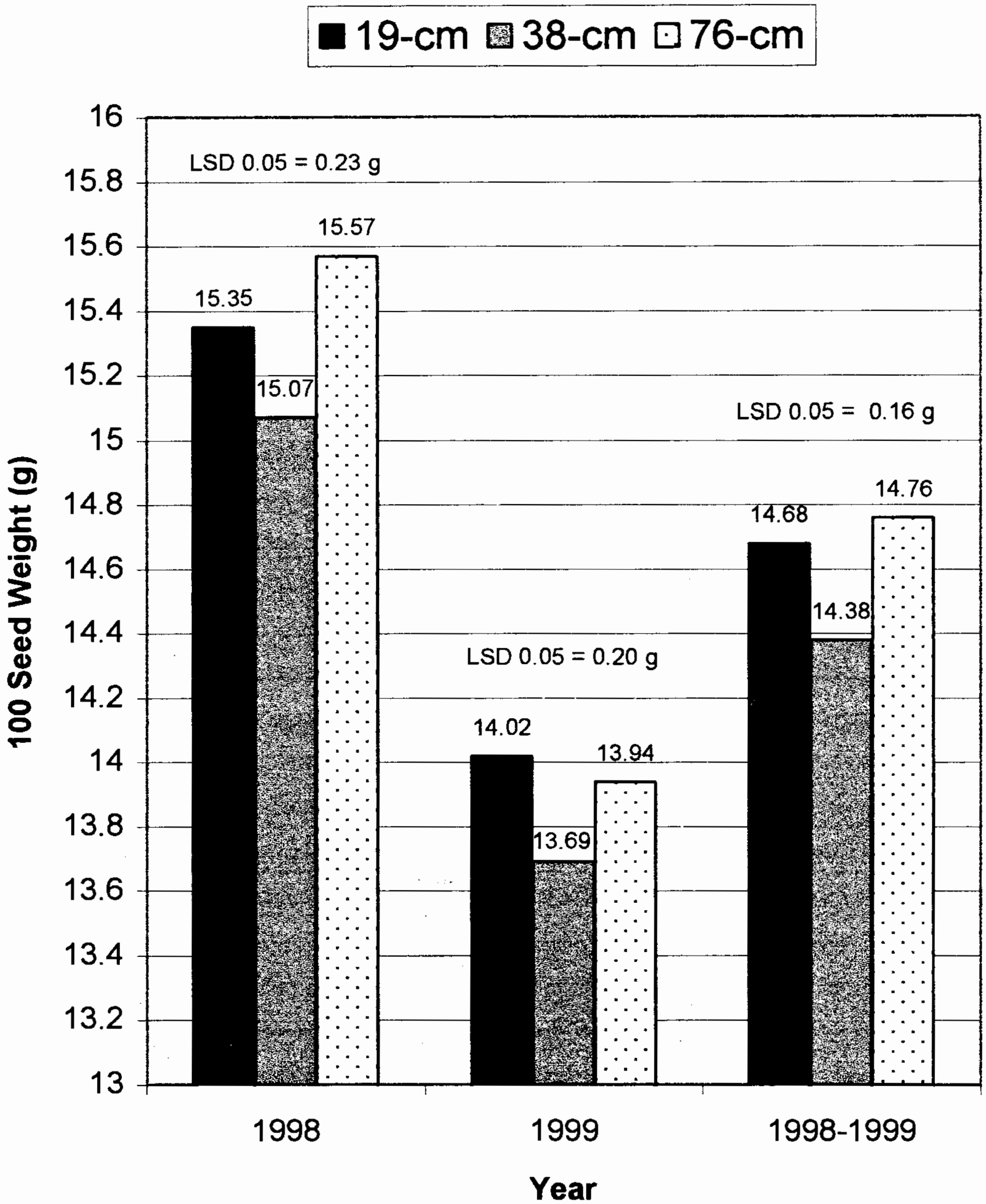
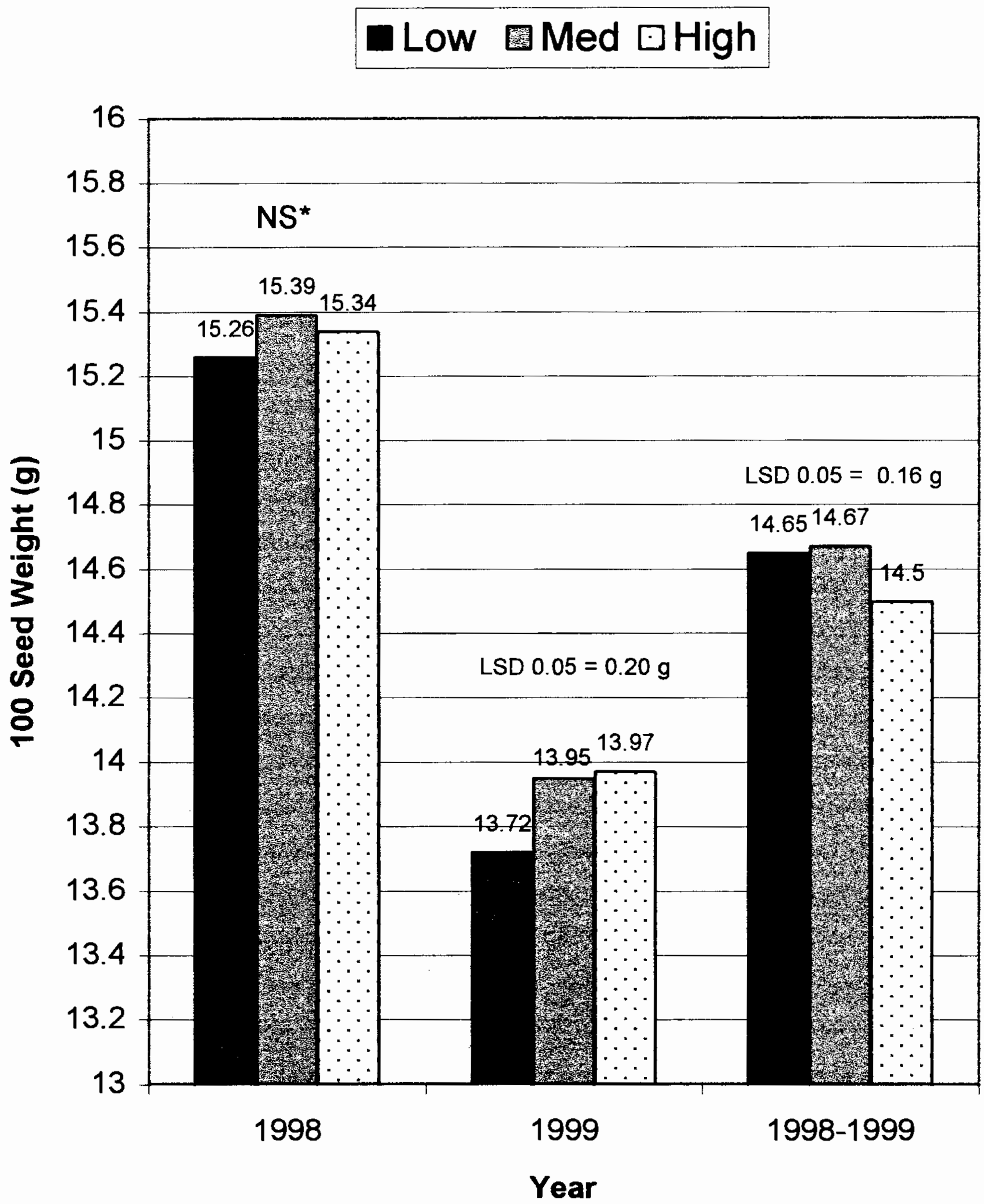


Figure 38. Row spacing effect on 100-seed weight at the Ames location (1998, 1999, and 1998-1999).



*NS denotes no significant statistical difference at the (P=0.05) level.

Figure 39. Seeding rate effect on 100-seed weight at the Ames location (1998, 1999, and 1998-1999).

Nashua 1999

Summary of season growing conditions

The 1999 growing season in northeast Iowa was characterized by above normal precipitation during all months of the growing season. Planting conditions were more favorable and the late season conditions were less stressful at this location compared to the location near Ames.

Yield

The yield average was 3348 kg/ha at the northeast location, 16% greater than that of the experiment near Ames. The yield advantage largely was the result of a lack of stressful environmental conditions during the seed filling and pod production stages. Another reason for the increased yields may have been the reduced amount of weed competition, as compared to the plots near Ames. Weed pressure was minimal at the beginning stages of soybean growth and was fairly non-existent after the applications of glyphosate were applied to the glyphosate tolerant variety. Average treatment yields are summarized in Table 4.

Main effects of planting date on soybean yield

Planting date significantly affected soybean yield in 1999 when averaged across all row spacings and plant populations (Figure 40). Planting delays reduced soybean yield potential; however, the yield reduction was not statistically significant until the second delay in planting. Soybeans planted on the first two dates produced similar yields, but yields associated with the third planting date were significantly reduced. Soybeans planted on the

Table 4. Mean yields and harvest plant populations for all treatments at the Northeast Research and Demonstration Farm near Nashua, 1999.

	Mean Treatment Yield	Harvest Plant Populations
	kg/ha	Plants/ha
Date 1		
25-cm Low[1]	3872	234,650
25-cm Med	4154	333,450
25-cm High	4140	434,720
51-cm Low	3610	200,070
51-cm Med	4000	328,510
51-cm High	4134	400,140
76-cm Low	3408	214,890
76-cm Med	3509	326,040
76-cm High	3650	414,960
Date 2		
25-cm Low	3590	264,290
25-cm Med	3664	330,980
25-cm High	3617	414,960
51-cm Low	3623	256,880
51-cm Med	3704	326,040
51-cm High	3731	419,900
76-cm Low	3610	202,540
76-cm Med	3677	330,980
76-cm High	3664	419,900
Date 3		
25-cm Low	2373	229,710
25-cm Med	2494	316,160
25-cm High	2642	456,950
51-cm Low	2407	214,890
51-cm Med	2628	306,280
51-cm High	2844	407,550
76-cm Low	2407	209,950
76-cm Med	2615	288,990
76-cm High	2702	400,140

[1]Seeding rate were 247,000 plants/ha (Low), 402,610 plants/ha (Med), and 555,750 plants/ha (High).

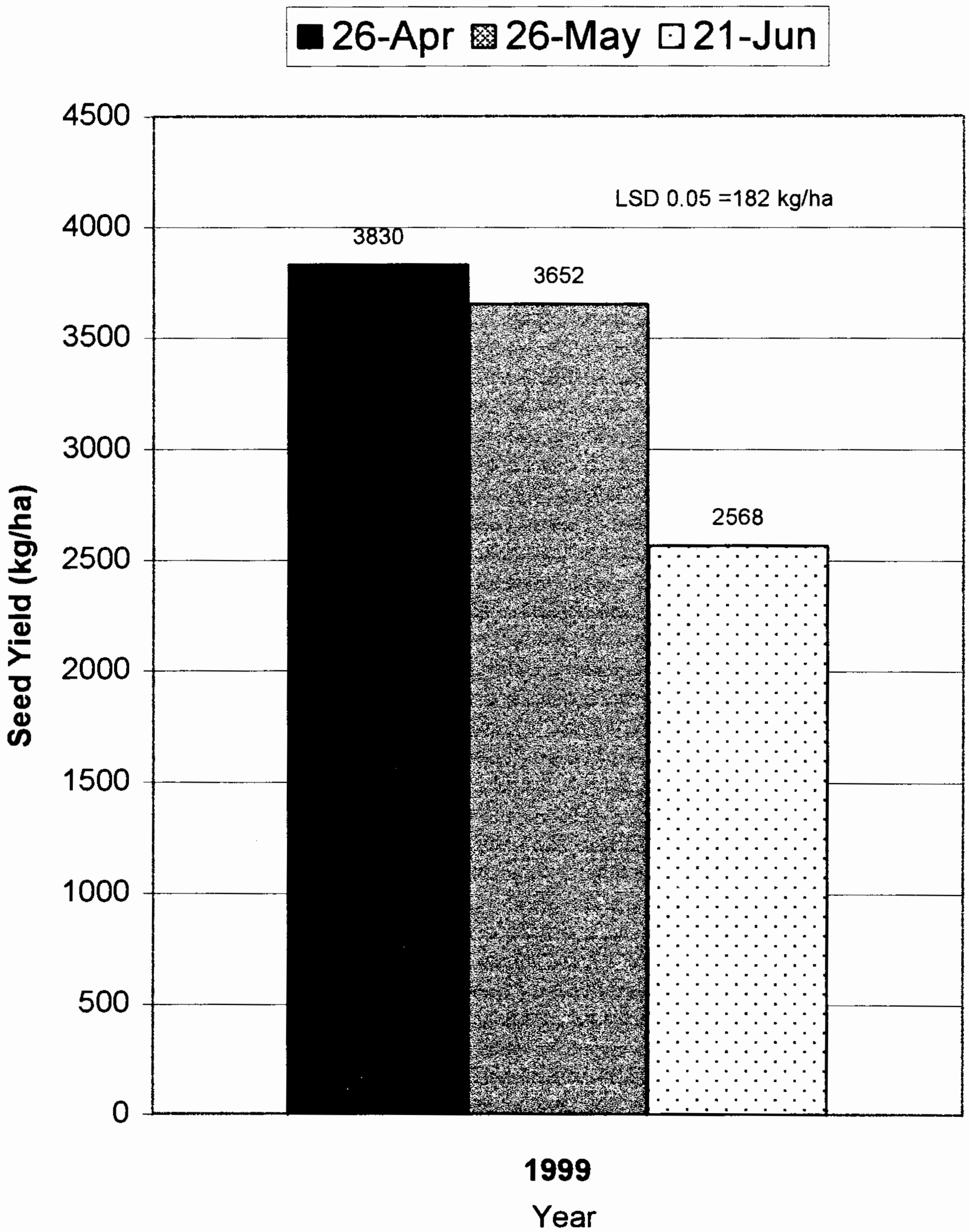


Figure 40. Mean yields for planting dates averaged over three seeding rates and three row spacings at the Nashua location (1999).

third planting date produced average yields that were 33 and 30% lower than those planted on Dates One and Two, respectively.

Main effects of row spacing on soybean yield

Row spacing affected yield differently at this location than it did at the location near Ames. Soybean yield increased as row spacing was decreased from 76-cm to 25-cm (Figure 41). Soybeans planted in 25- and 51-cm rows produced similar yields; however, both yielded significantly more than those planted in 76-cm rows. Past studies have indicated that soybean yield response to narrow rows increases at northern latitudes (Hugie and Orf, 1989; Leuschen et al., 1992).

Main effects of seeding rate on soybean yield

Seeding rate had a significant effect on soybean seed yield at this location (Figure 42). Each increase in seeding rate resulted in a significant yield increase. Seeding rate responses have varied in the past. Several researchers have indicated no significant yield responses over a large range of seed rates (Wilcox, 1974; Carpenter and Board, 1997). Others have reported a yield decrease as seeding rates are increased (Williamson, 1974; Albett et al., 1991). Several studies also have found results that indicate a yield increase as seeding rates are increased (Oplinger and Philbrook, 1992; Delvin et al., 1995; Wykle, 1997). The yield response to increased seeding rates may be partially the result of increased interplant competition, which caused an increase in average plant height and growth rate. This response may have led to an increase in rate of leaf area index accumulation (Weber et al., 1966). The faster growth rate and larger plant height reduced the time needed to reach

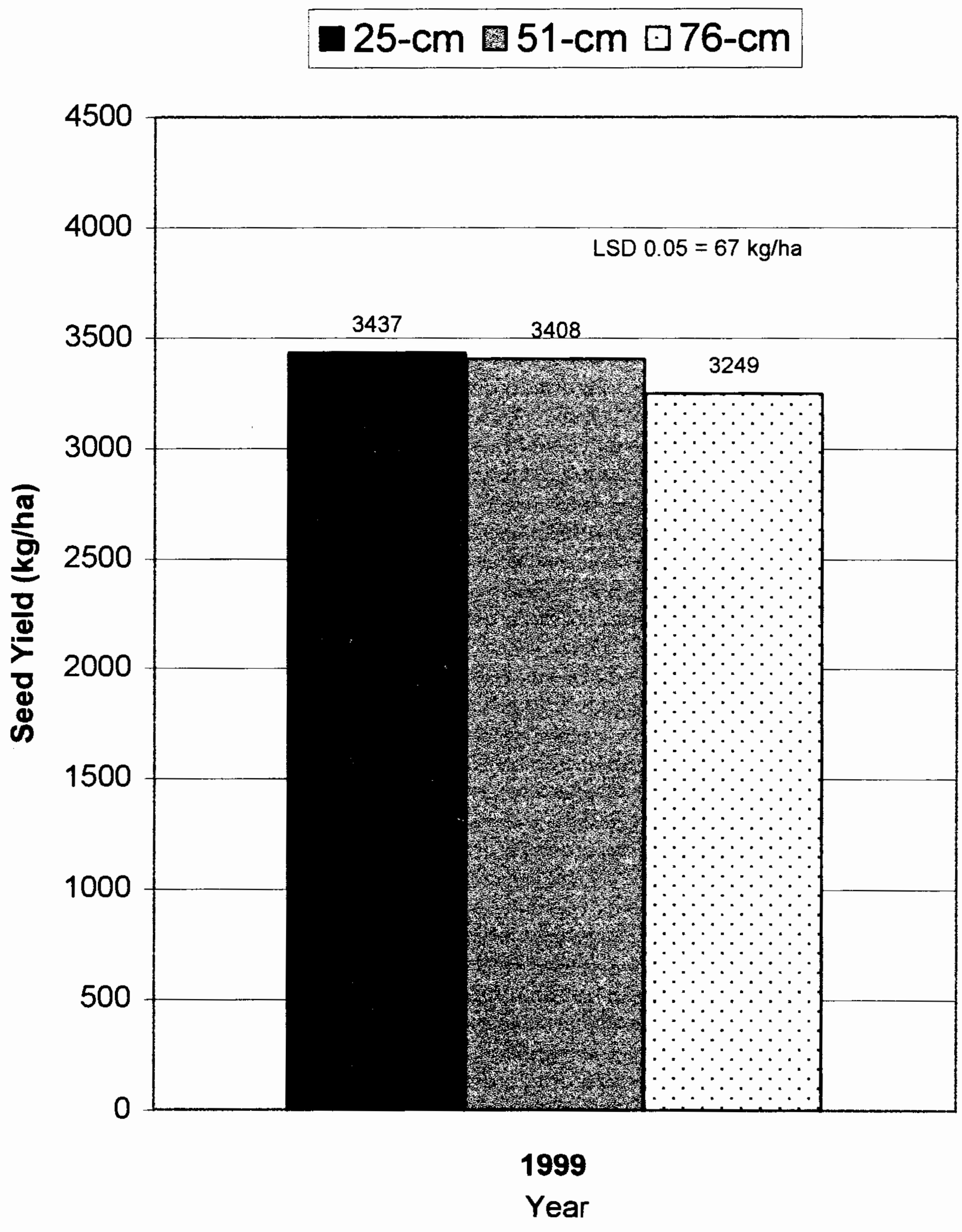


Figure 41. Mean yields for row spacings averaged over three planting dates and three seeding rates at the Nashua location (1999).

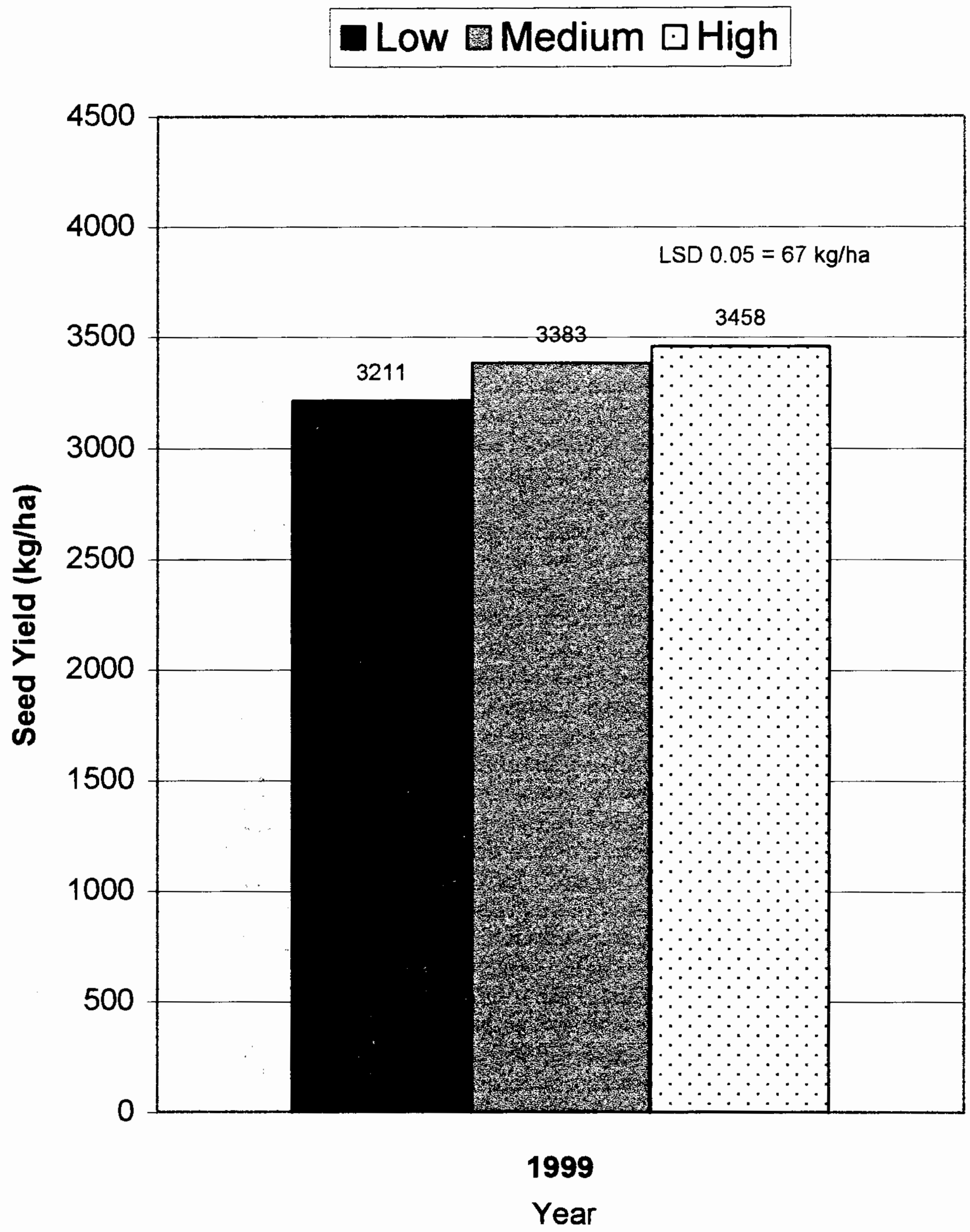


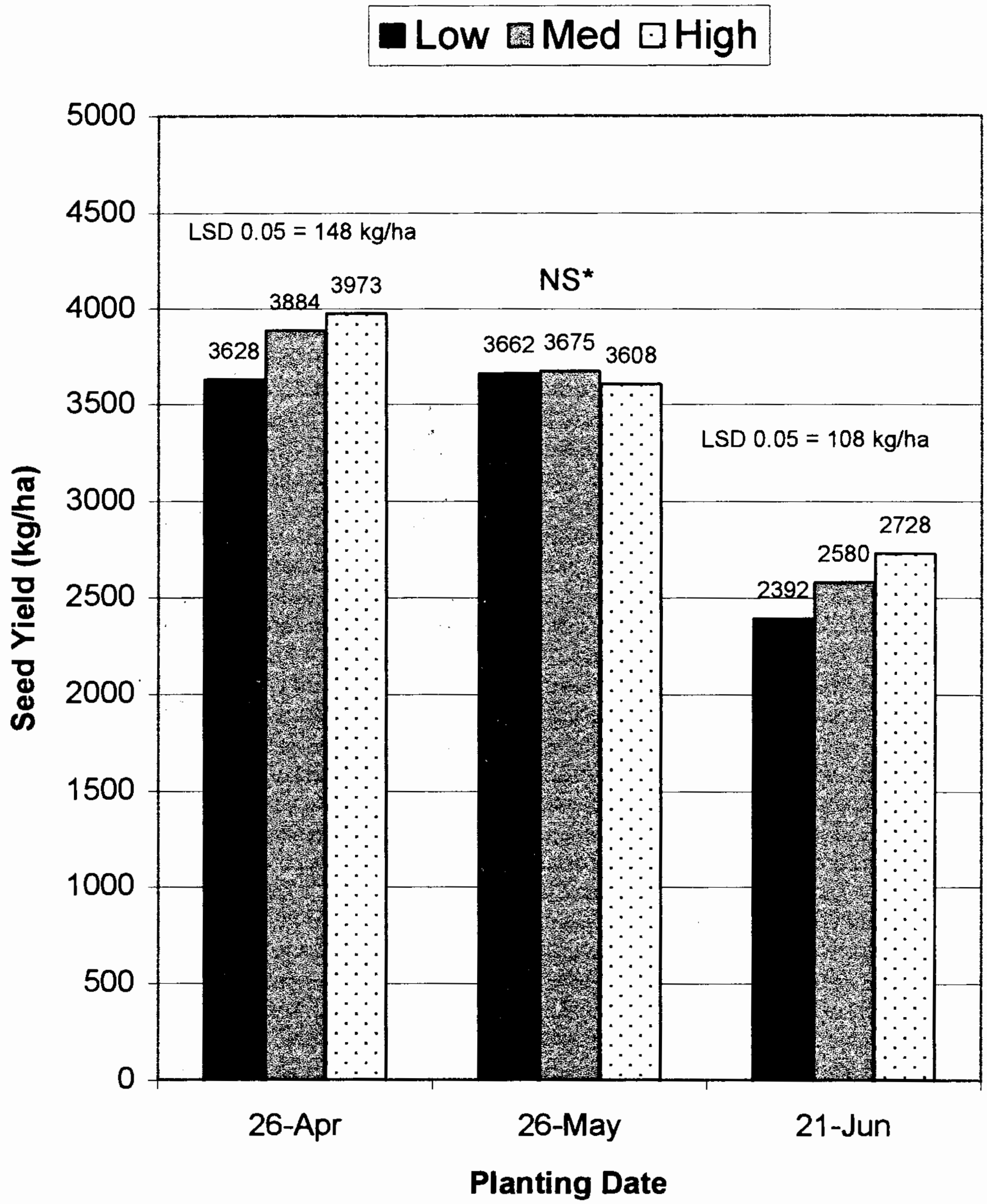
Figure 42. Mean yields for seeding rates averaged over three planting dates and three row spacings at the Nashua location (1999).

full canopy prior to the seed filling period. In this experiment, seeding rate had a significant effect on plant height and, therefore, may have helped the canopy to close sooner, allowing plants to intercept more of the available sunlight during seed filling. Harvest plant populations were much more consistent and closer to the targeted rates in this experiment than in the location near Ames. Individual treatment means for harvested plant populations can be seen on Table 4.

Interactive effects of planting date, row spacing, and seeding rate combinations on soybean yield

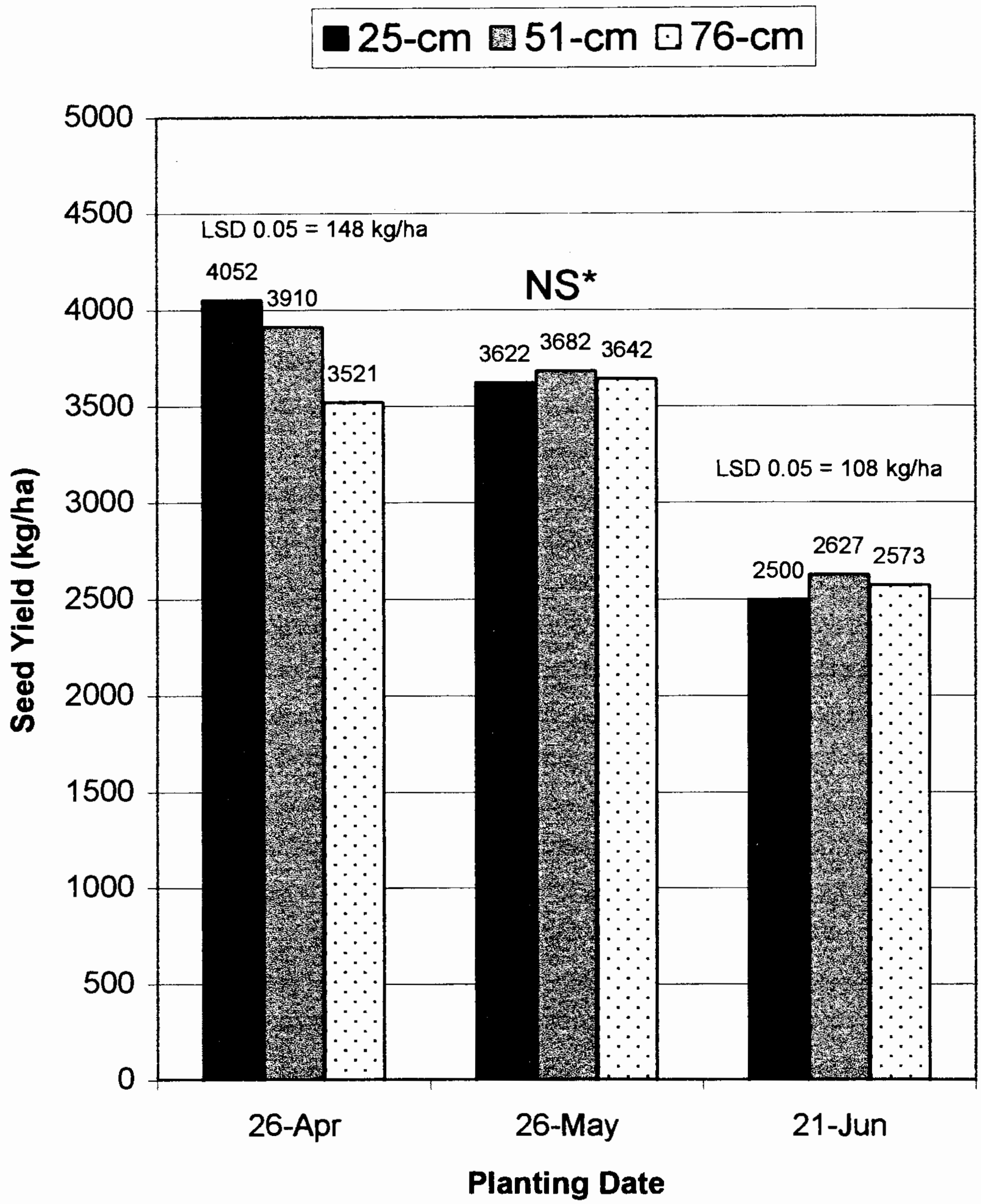
Planting date in this experiment influenced soybean seed yield response to seeding rate. Figure 43 illustrates that a yield response to seeding rate occurred with the first and third planting dates. The second planting date did not produce a significant soybean yield response to seeding rate. Soybeans planted on the first date showed a significant yield increase as seeding rate was increased from the low to the medium level. The additional increase from the medium to the high level did not result in a significant yield difference. Soybeans planted on the third date responded similarly; however, yields continued to increase for each increase in seeding rate. Past studies have indicated that increasing seeding rates for late-planted soybeans can significantly increase seed yields (Beuerlein, 1988). The difference in seeding rate yield response on each planting date in this experiment suggests a significant planting date by seeding rate interaction ($P = 0.004$).

Planting date also influenced the soybean seed yield response to row spacing. As shown in Figure 44, soybeans planted on the first and third planting dates had a significant yield response to row spacing, while those planted on the second planting date did not



*Within a planting date,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 43. Planting date influence on soybean yield response to seeding rate at the Nashua location (1999).



*Within a planting date, "NS" denotes no significant statisitcal differences at the (P=0.05) level.

Figure 44. Planting date influence on soybean yield response to row spacing at the Nashua location (1999).

significantly respond to different row spacings. Yield of soybeans planted on the first date declined as row spacing increased to 76-cm, although soybeans planted in 25- and 51-cm rows yielded similarly. Soybeans planted on the second date yielded similarly regardless of row spacing. Soybeans planted on Date Three yielded best in 51-cm rows, with 76-cm rows yielding similar and 25-cm rows yielding less. These yield results differ from some previously reported work, where late-planted soybean yields increased significantly as row spacing narrowed (Cartter and Hartwig, 1963; Ryder and Beuerlein, 1979). In this study, the inconsistent row spacing yield response on different planting dates produced a significant planting date by row spacing interaction ($P = 0.0001$).

Figure 45 indicates that row spacing influenced the soybean yield response to seeding rate in this experiment. The trend is similar for each of the three row spacings but statistically they differed slightly. Soybeans planted in 25- and 51-cm rows responded to an increase in seeding rate from the low to the medium rate; however, an additional increase to the high rate did not significantly change yield. Soybeans planted in 76-cm rows responded to increases in seeding rate, although yield increases were not as significant. Increasing from the low seeding rate to the high seeding rate produced significantly higher yields, with the medium seeding rate producing an average yield similar to both the low and high rates. The overall row spacing by plant population interaction was not significant ($P = 0.22$).

Figures 46-48 illustrate the combination of all three variables in this study. The planting date by row spacing by seeding rate interactions can be seen within and across these figures. The individual figures illustrate the influence of planting date on yield response to seeding rate within a single row spacing. The planting date by row spacing influence on yield response to seeding rate can be seen by looking across these three figures. The trend

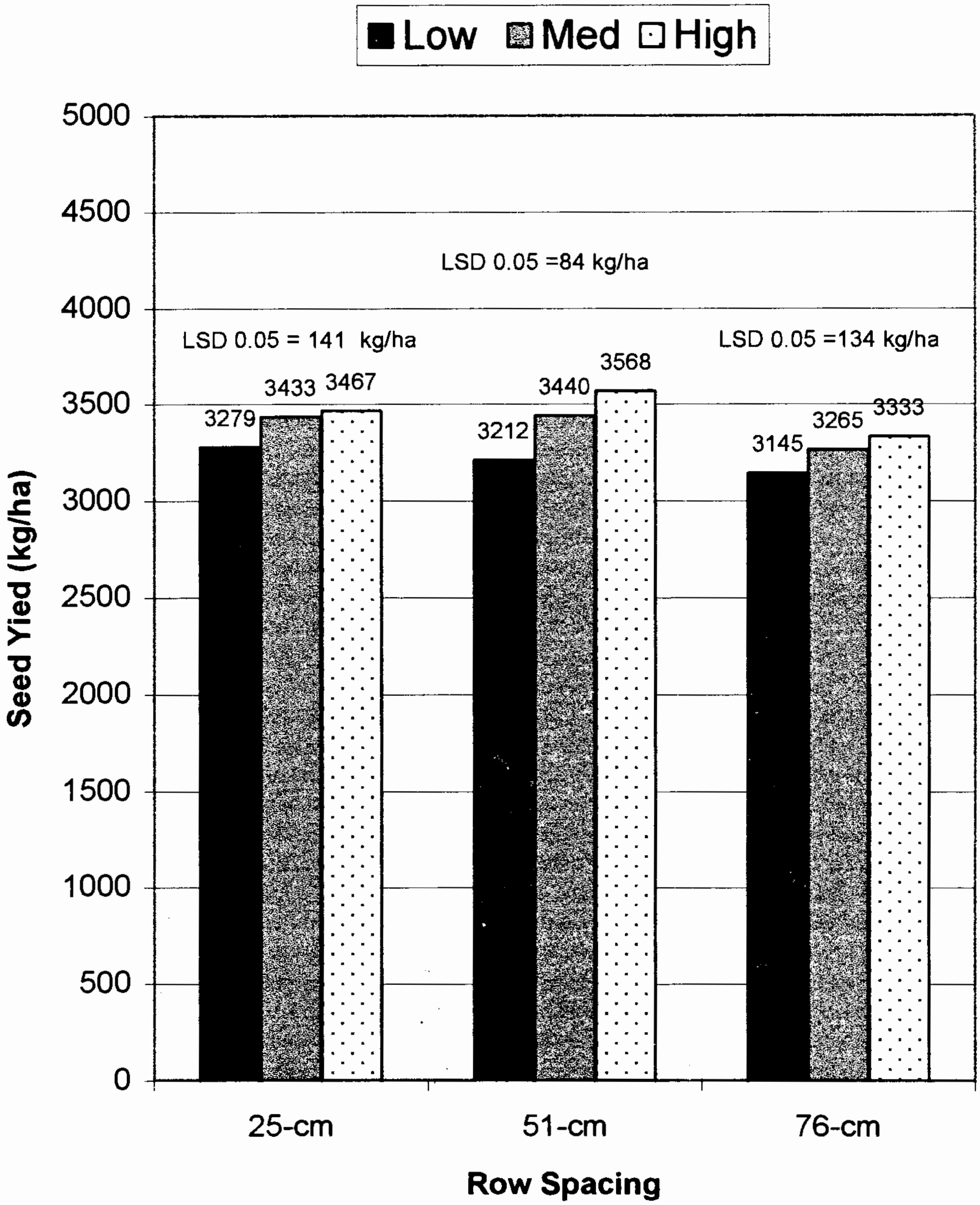
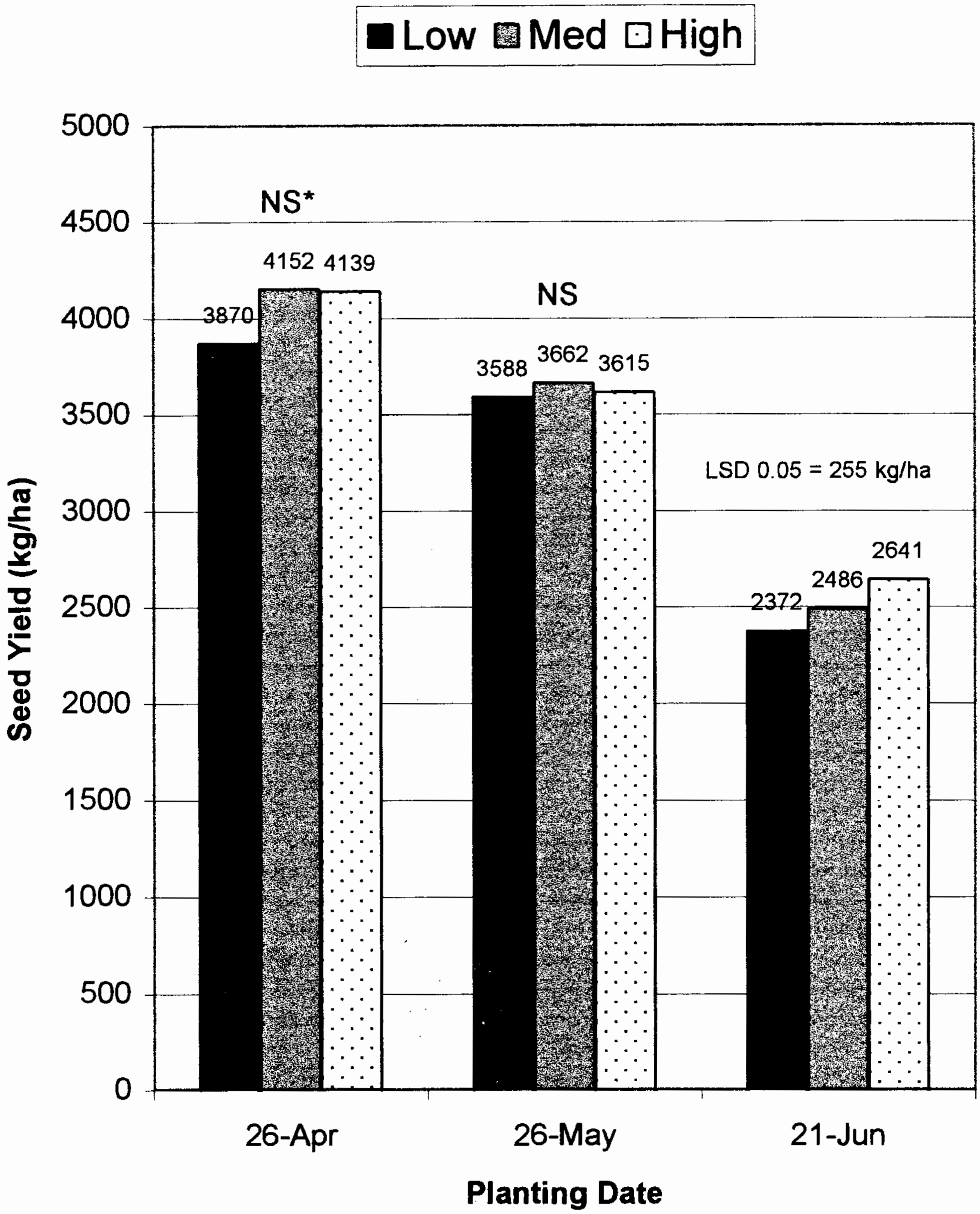


Figure 45. Row spacing influence on soybean yield response to seeding rate at the Nashua location (1999).



*Within a planting date,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 46. Planting date influence on soybean seed yield response to seeding rate in 25-cm rows at the Nashua location (1999).

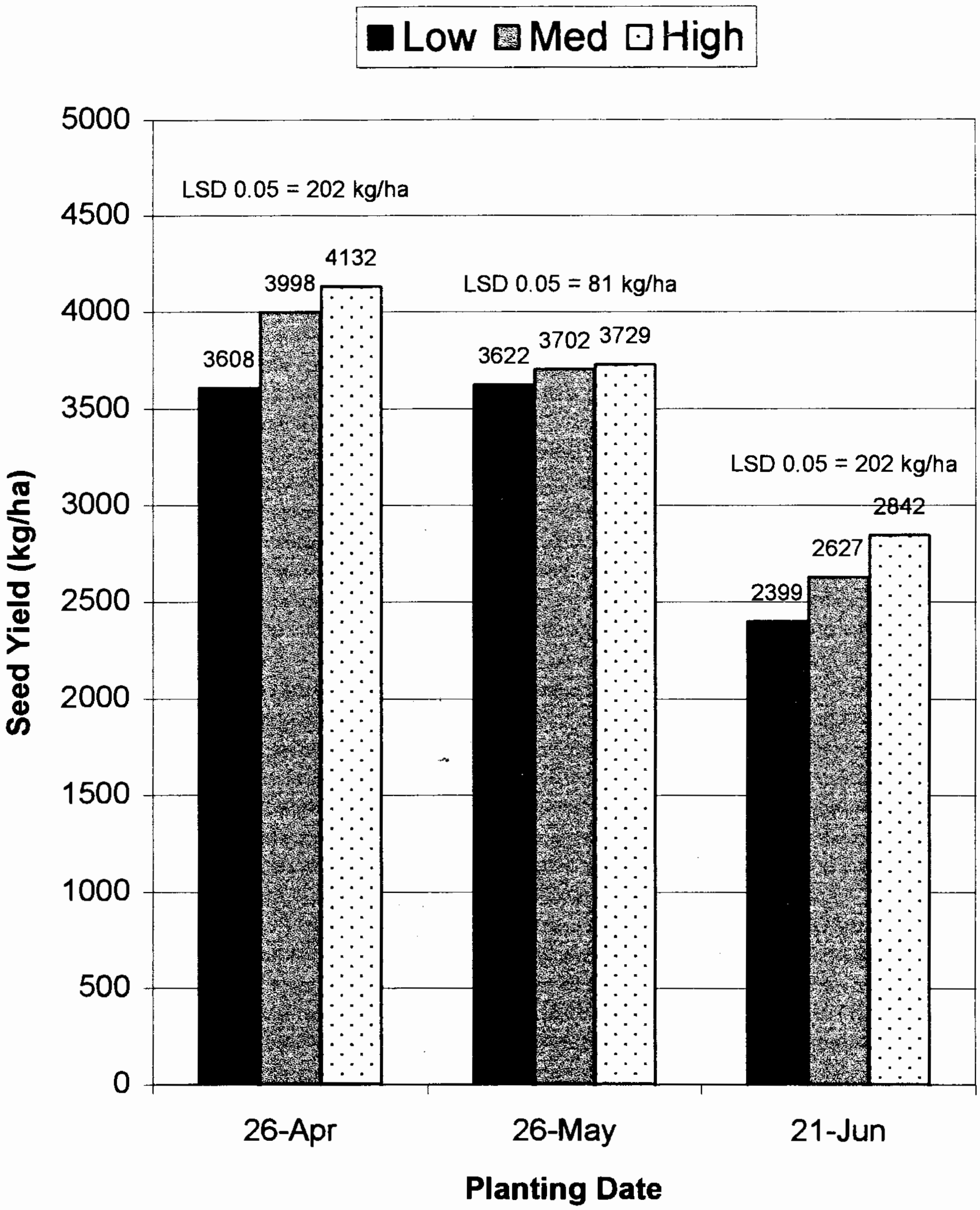
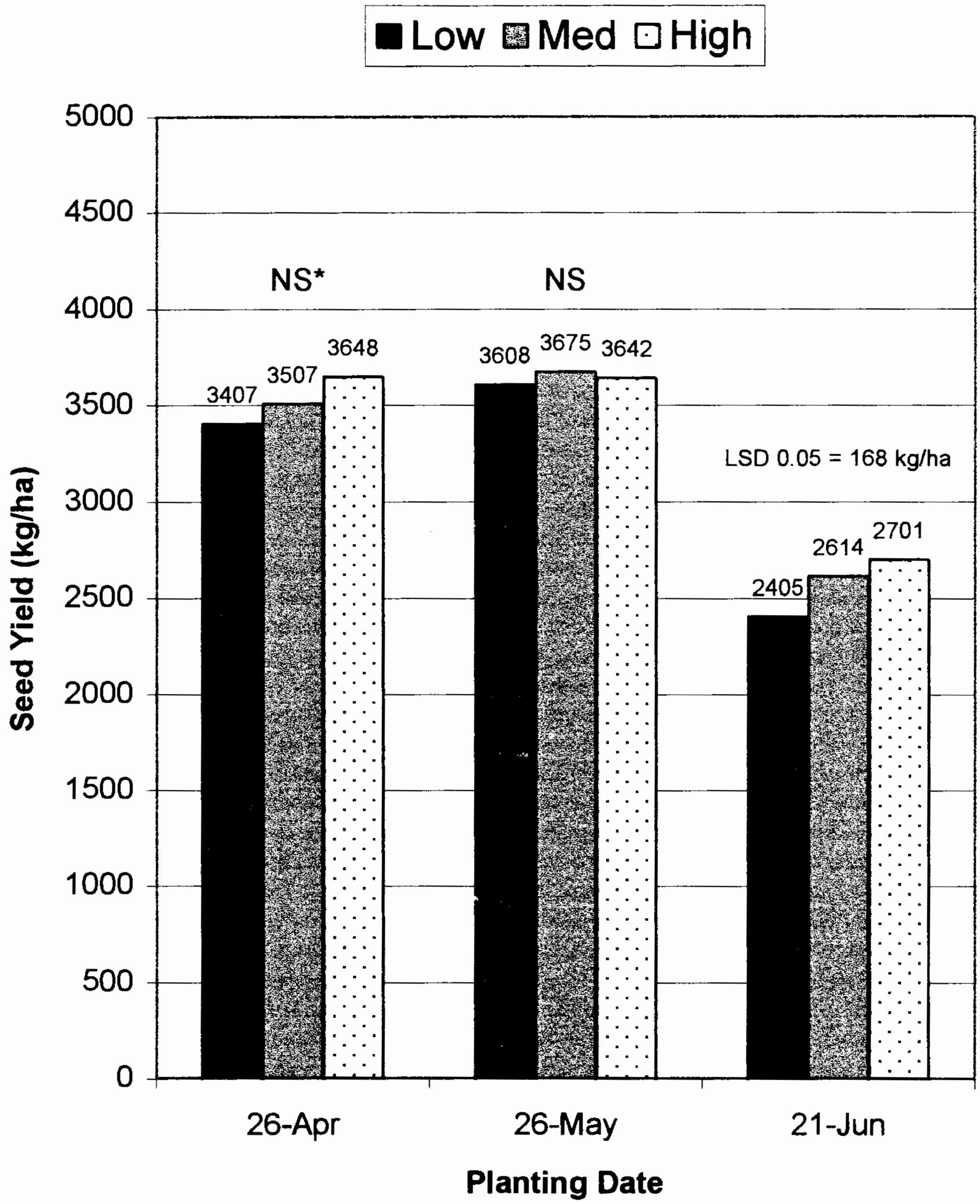


Figure 47. Planting date influence on soybean seed yield response to seeding rate in 51-cm rows at the Nashua location (1999).



*Within a planting date,"NS" denotes no significant statistical differences at the (P=0.05) level.

Figure 48. Planting date influence on soybean seed yield response to seeding rate in 76-cm rows at the Nashua location (1999).

across all of the figures is similar, indicating that there was no planting date by row spacing by seeding rate interaction ($P = 0.87$) in this experiment.

Effects of planting date, row spacing, and plant population on soybean plant height and yield components

Soybean yields are determined by a combination of yield components. Pods per plant, seed number, and seed size/weight are three key components in soybean yield. In this study plant height, number of pods per plant, number of seeds per kilogram, 100-seed weight, and number of seeds per pod were evaluated. In many cases treatments had a significant influence on these yield components. Table 5 provides treatment means for all of the yield components measured. Number of seeds per pod are excluded from the presented data due to a lack of response to treatments.

As shown in Figure 49, planting date significantly affected the soybean plant height. Soybeans planted on the second planting date were 16 and 19% taller than those planted on the first and third planting dates, respectively. This result can be attributed to the shorter time for vegetative growth with Date Three and the cool, early season temperatures with Date One This agrees with findings by Beaver and Johnson (1981) and Anderson and Vasilas (1985).

Plant height did respond slightly to row spacing. Figure 50 illustrates that soybeans planted in 25- and 51-cm rows attained similar plant heights, and that soybeans planted in 76-cm rows were significantly shorter than those in the 25- and 38-cm rows. The statistical analysis indicated that this difference in plant height was significant but the plant height differences were fairly minimal and most likely did not attribute to any yield differences.

Table 5. Means for yield components for all treatments at the Northeast Research and Demonstration Farm near Nashua, 1999.

Date 1	Plant Heights (cm)	Pods/Plant	Seeds/kg	100-Seed Weight (g)
25-cm Low[1]	79[2]	78	1612	13.37
25-cm Med	81	62	1540	13.93
25-cm High	81	53	1618	13.28
51-cm Low	76	75	1585	14.41
51-cm Med	84	53	1602	14.72
51-cm High	81	49	1596	15.24
76-cm Low	76	78	1635	13.06
76-cm Med	79	58	1613	14.23
76-cm High	81	45	1586	14.94
Date 2				
25-cm Low	94	59	1440	13.58
25-cm Med	97	42	1412	13.61
25-cm High	97	32	1407	13.57
51-cm Low	91	57	1422	14.53
51-cm Med	97	46	1398	15.21
51-cm High	97	30	1387	15.16
76-cm Low	91	51	1458	13.06
76-cm Med	94	37	1422	14.23
76-cm High	94	32	1442	14.94
Date 3				
25-cm Low	71	52	1622	13.26
25-cm Med	76	33	1542	13.37
25-cm High	81	25	1460	13.18
51-cm Low	71	52	1642	14.92
51-cm Med	76	32	1484	15.43
51-cm High	79	27	1430	15.11
76-cm Low	74	43	1604	13.64
76-cm Med	76	32	1568	13.52
76-cm High	76	24	1494	14.28

[1]Seeding rate were 247,000 plants/ha (Low), 402,610 plants/ha (Med), and 555,750 plants/ha (High).
[2]Heights were measured from the soil surface to the terminal pod of the top node on the main stem at physiological maturity (R8).

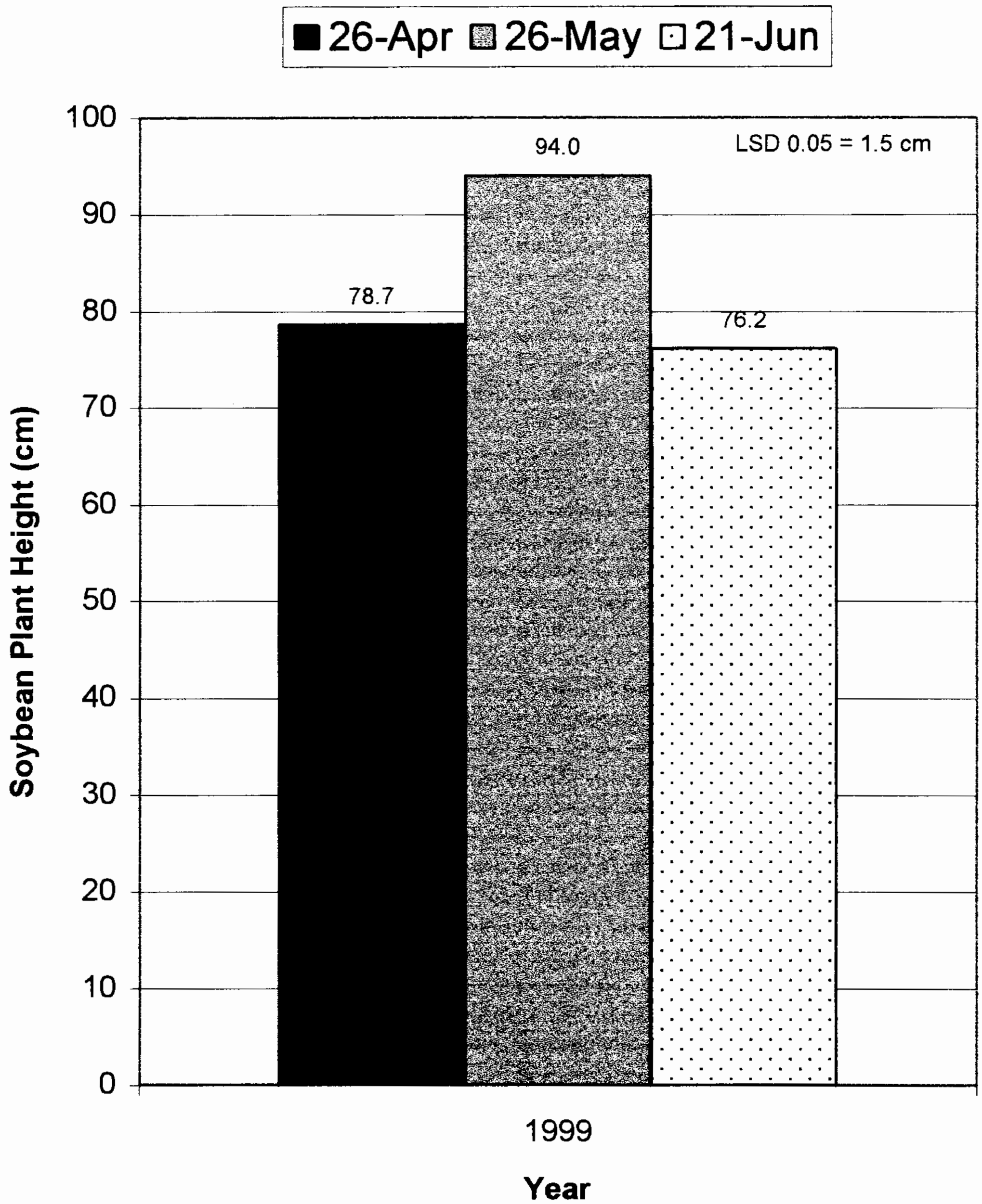


Figure 49. Planting date effect on soybean plant height at the Nashua location (1999).

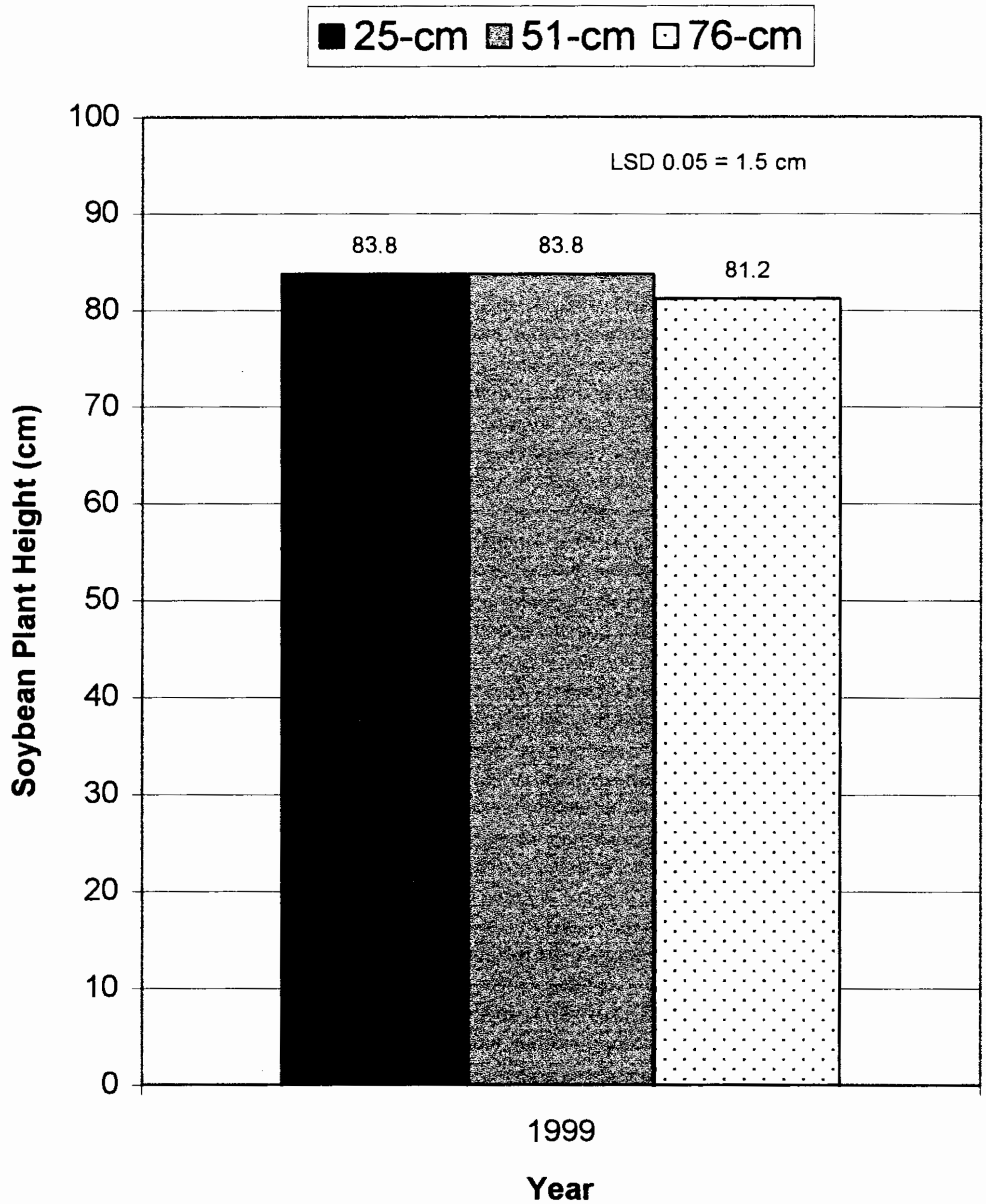


Figure 50. Row spacing effect on soybean plant height at the Nashua location (1999).

The lack of plant lodging also provides evidence that the plant height differences were not significant. Row spacing influence on plant height has been very inconsistent in past research, suggesting that other variables, such as planting date and plant population, are more important in plant height determination (Taylor, 1980; Bharati, 1984).

Seeding rate affected plant height significantly in this study. Figure 51 shows that as seeding rate increased, plant height increased as well. Many reports have indicated this relationship in the past (Cooper, 1971b; Wykle, 1997; Tranel, 1999). The increase in seeding rate increases the interplant competition for available sunlight, creating this effect (Alessi and Power, 1982).

Figure 52 illustrates the influence of planting date on pod production. There was a significant decrease in pod production as planting date was delayed. This result may have been the key component in determining the harvested yield. The pod production and yield averages for each date are directly proportional.

Figure 53 shows the effect of row width on pod production. Pod production per plant increased as row spacing narrowed. Past studies have indicated that soybeans compensate for increased within-row spacing by increasing per plant pod production (Enyi, 1973; Lueschen and Hicks, 1977). Figure 54 also supports these findings by indicating that per plant pod production was greatly affected by seeding rate. The number of pods produced per plant was significantly decreased with each increase in seeding rate.

Seeds per kilogram were affected by planting date at the Nashua location in 1999 (Figure 55). The smallest seeds (largest number of seeds per kilogram) were produced on the first planting date. The third planting date produced significantly fewer seeds per kilogram than Date One. Date Two produced the largest seed size (fewest number of seeds per

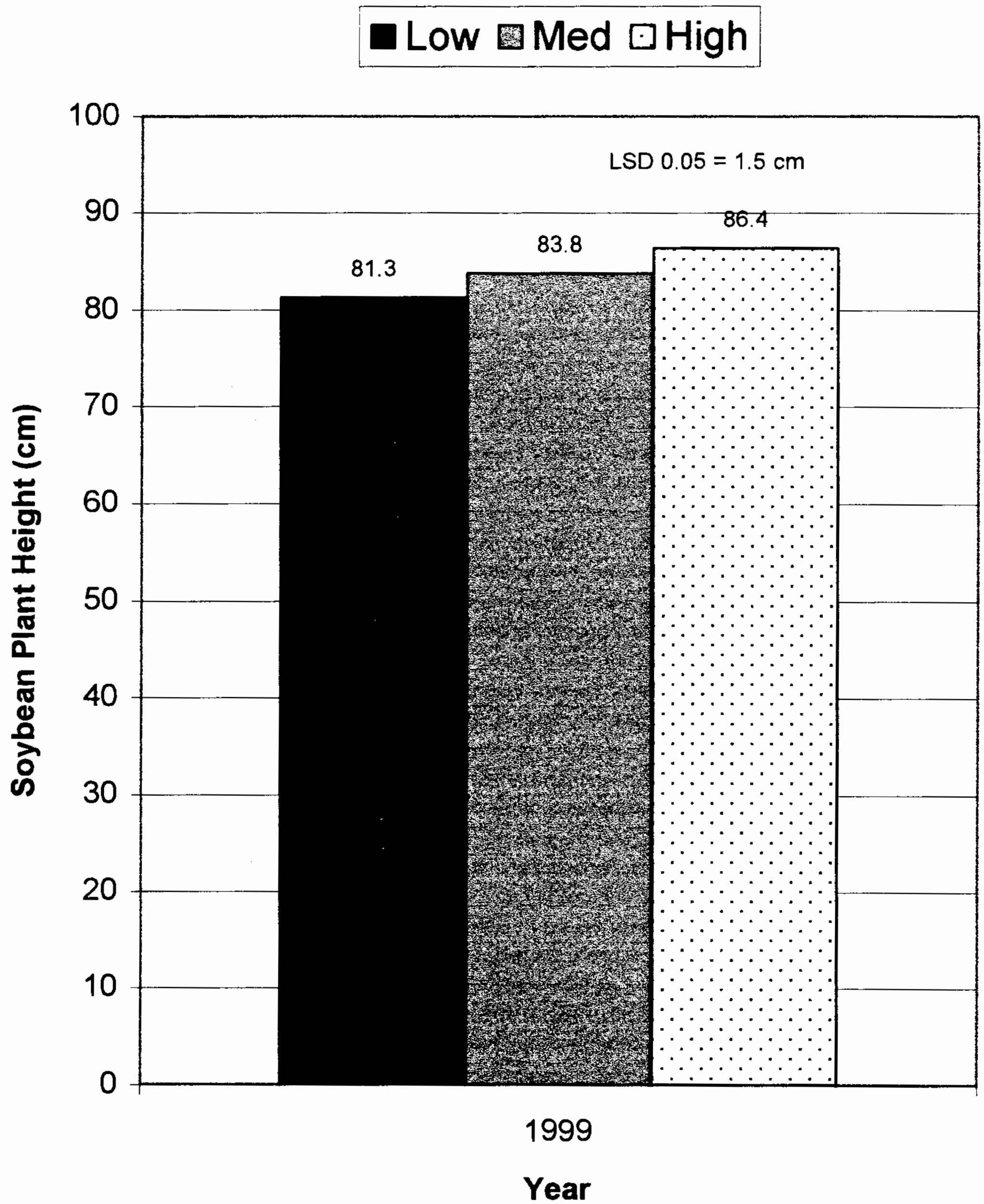


Figure 51. Seeding rate effect on soybean plant height at the Nashua location (1999).

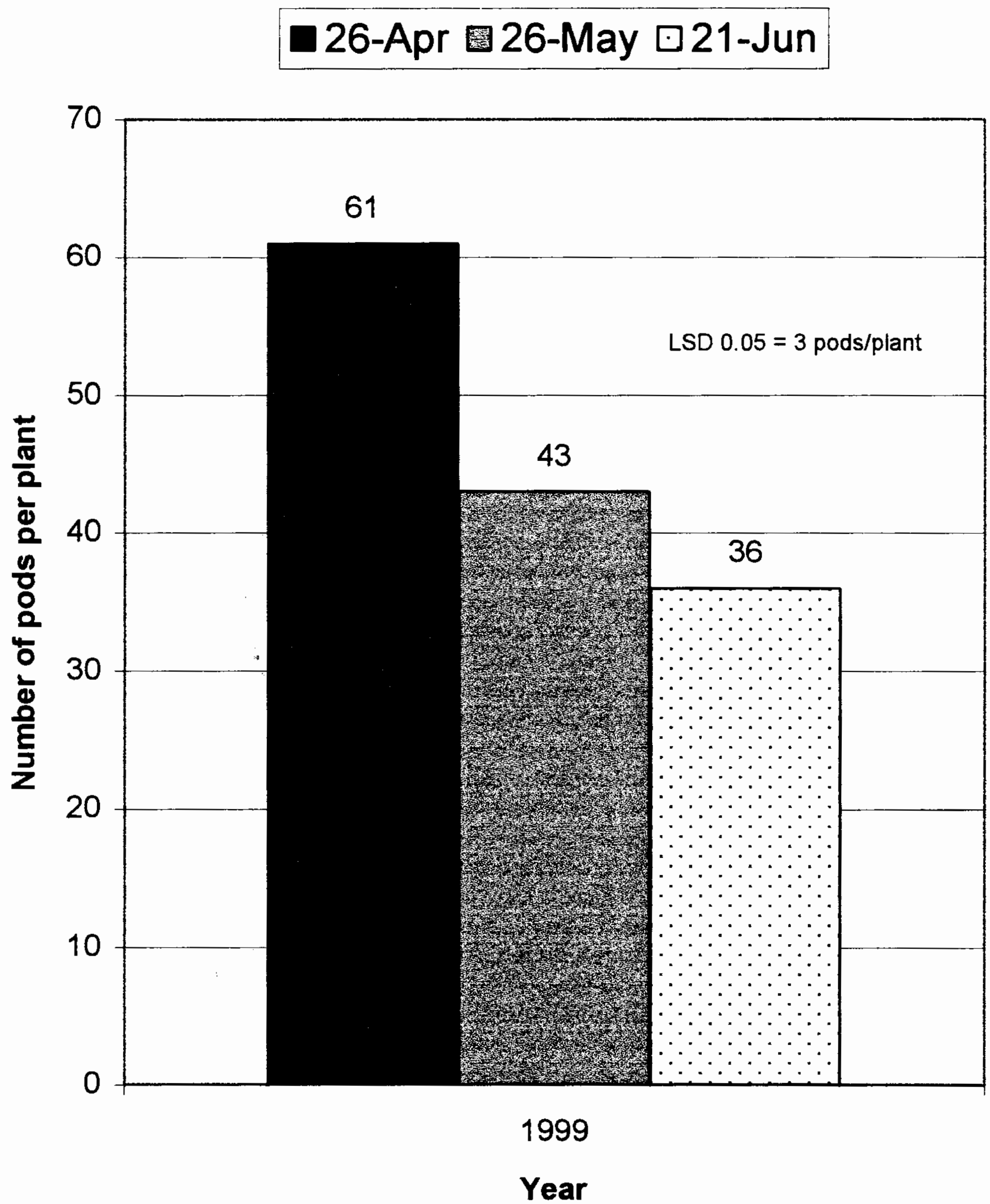


Figure 52. Planting date effect on number of pods per plant at the Nashua location (1999).

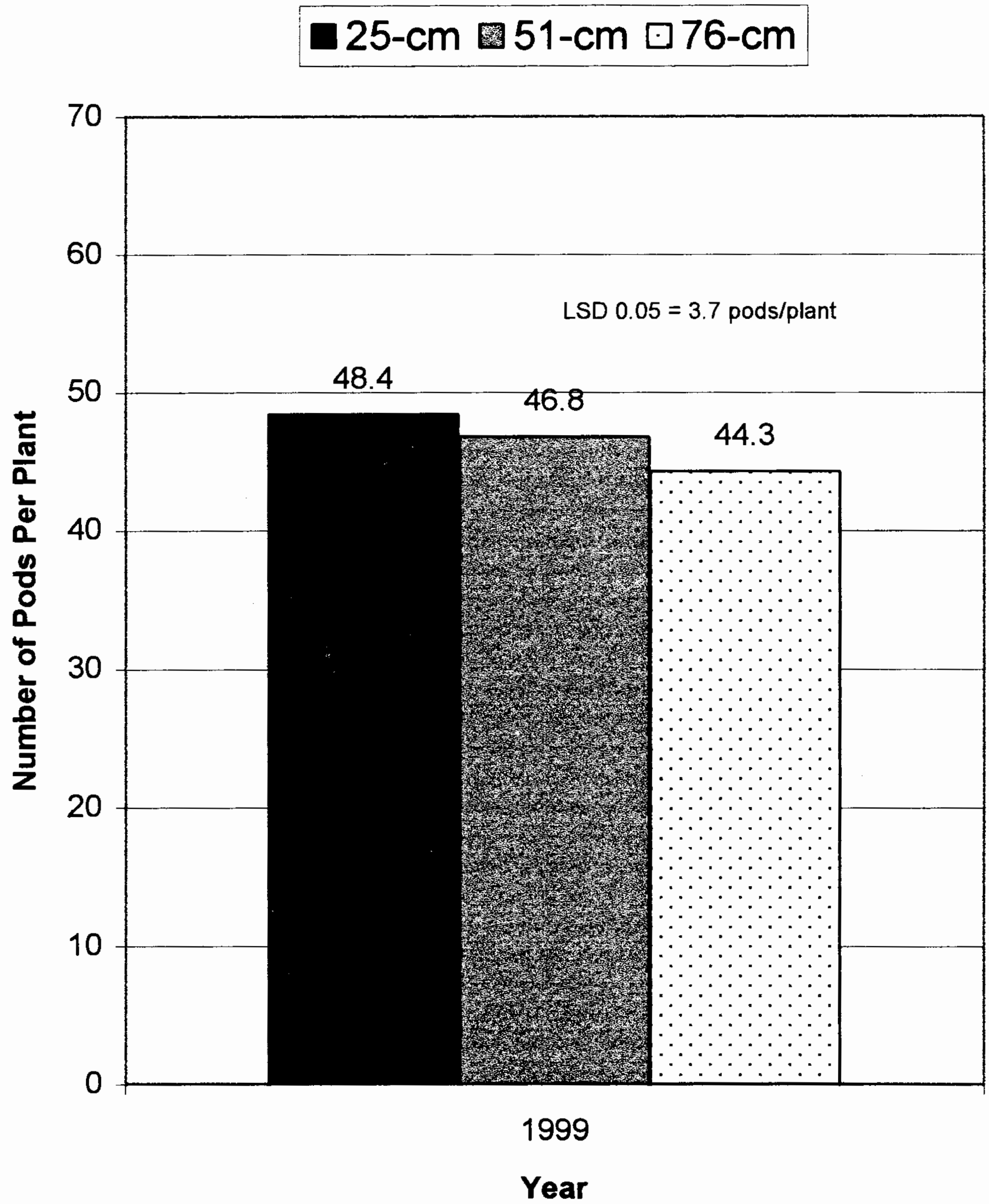


Figure 53. Row spacing effect on number of pods per plant at the Nashua location (1999).

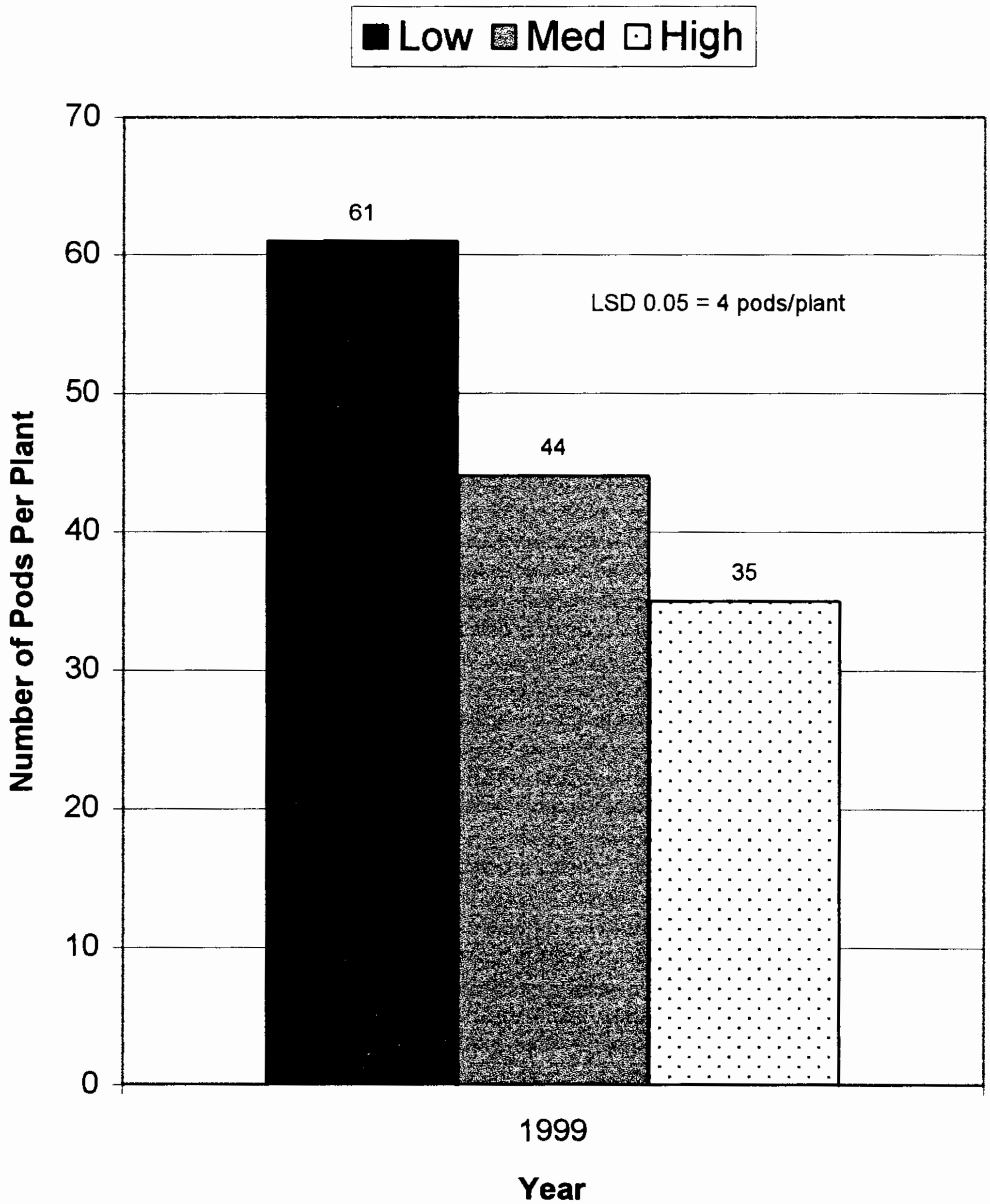


Figure 54. Seeding rate effect on number of pods per plant at the Nashua location (1999).

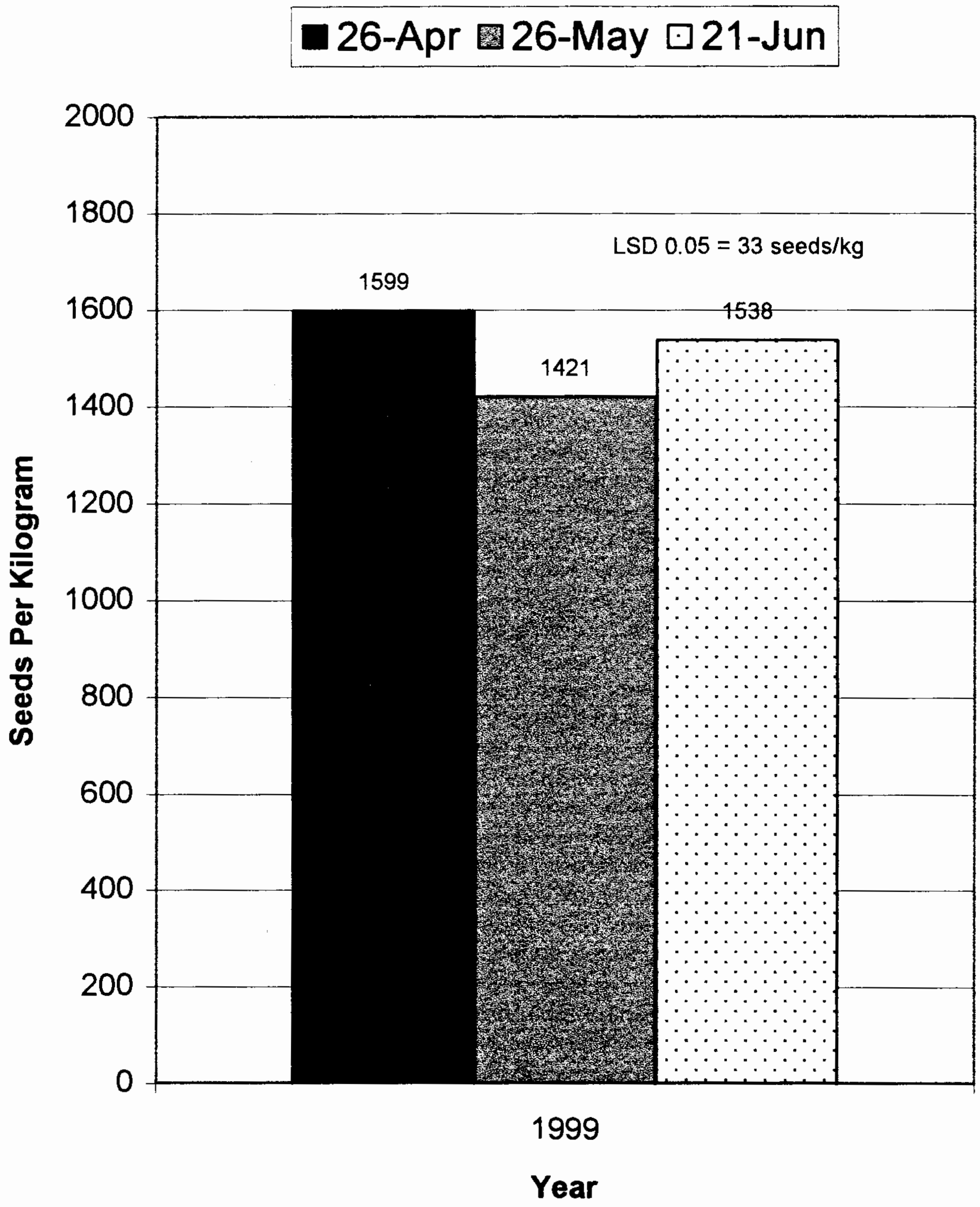


Figure 55. Planting date effect on number of seeds per kilogram at the Nashua location (1999).

kilogram). The additional vegetative growth may explain why Date Two produced the largest seeds. Growth conditions were extremely favorable and light interception was maximized by the beginning of the seed-filling stages allowing the plant to use its energy on seed production.

Row spacing had an influence on seeds per kilogram (Figure 56). Smallest seeds were produced (seeds per kilogram were maximized) when soybeans were planted in 76-cm rows, with soybeans planted in 51-cm rows producing the largest seeds (fewest seeds per kilogram) and 25-cm rows producing moderate-sized seeds. These data differ from some of the past reports that have indicated a seed size increase when row spacing was increased (Reiss and Sherwood, 1965). Other research has supported these data, suggesting that seed size is likely influenced more by planting date and seeding rate than by row spacing (Beatty et al, 1982; Alessi and Power, 1982). Figure 57 indicates that seeding rate does influence the number of seeds per kilogram. Seeds per kilogram decrease as seeding rate increases, suggesting that although there are more pods per plant at the lower seeding rates, seed yield advantages are offset by a decrease in seed size. Planting date also influenced the 100-seed weight at the Nashua location (Figure 58). The greatest 100-seed weight (largest seeds) were produced on the second planting date. Soybeans planted on Dates One and Three were significantly smaller (reduced 100-seed weight).

Figure 59 illustrates that 100-seed weight was not affected by changes in row spacing, suggesting that seed size and weight is determined primarily by planting date and seeding rate. Figure 60 supports this result by indicating significant seeding rate effects on 100-seed weight. The trend shows that seed weight is increased as seeding rate is increased. Increasing the seeding rate from the low to the medium rate resulted in a significantly higher

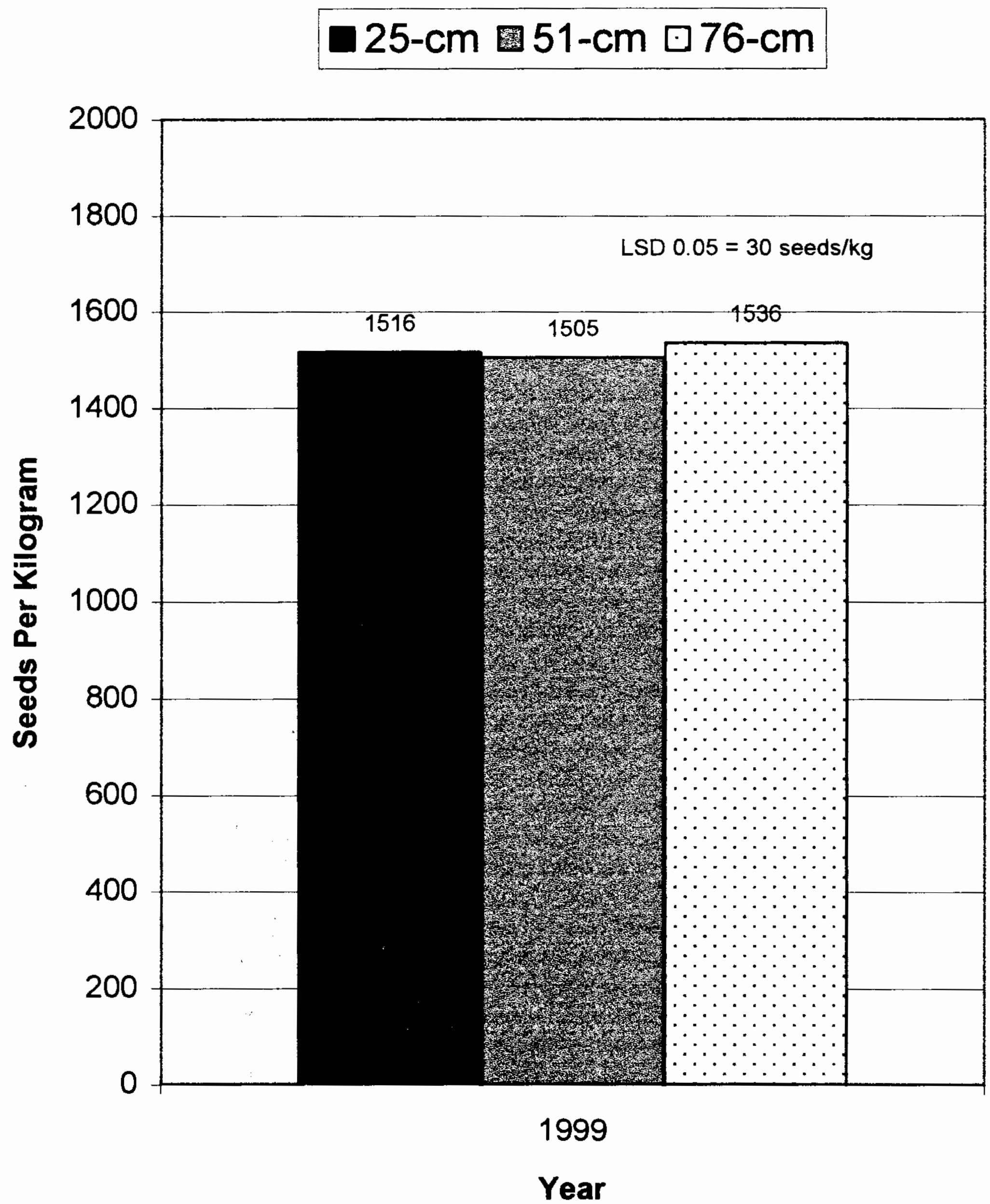


Figure 56. Row spacing effect on number of seeds per kilogram at the Nashua location (1999).

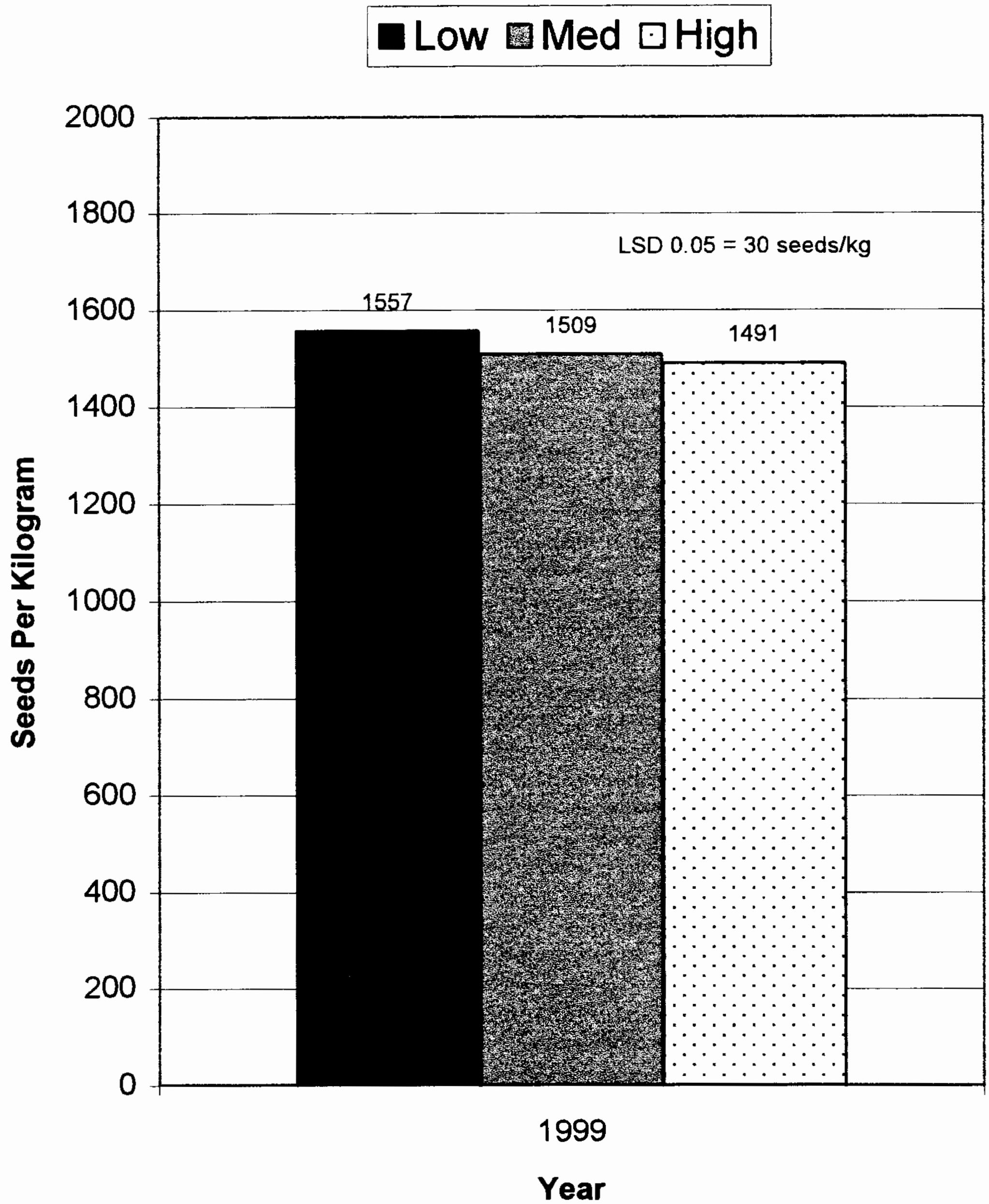


Figure 57. Seeding rate effect on number of seeds per kilogram at the Nashua location (1999).

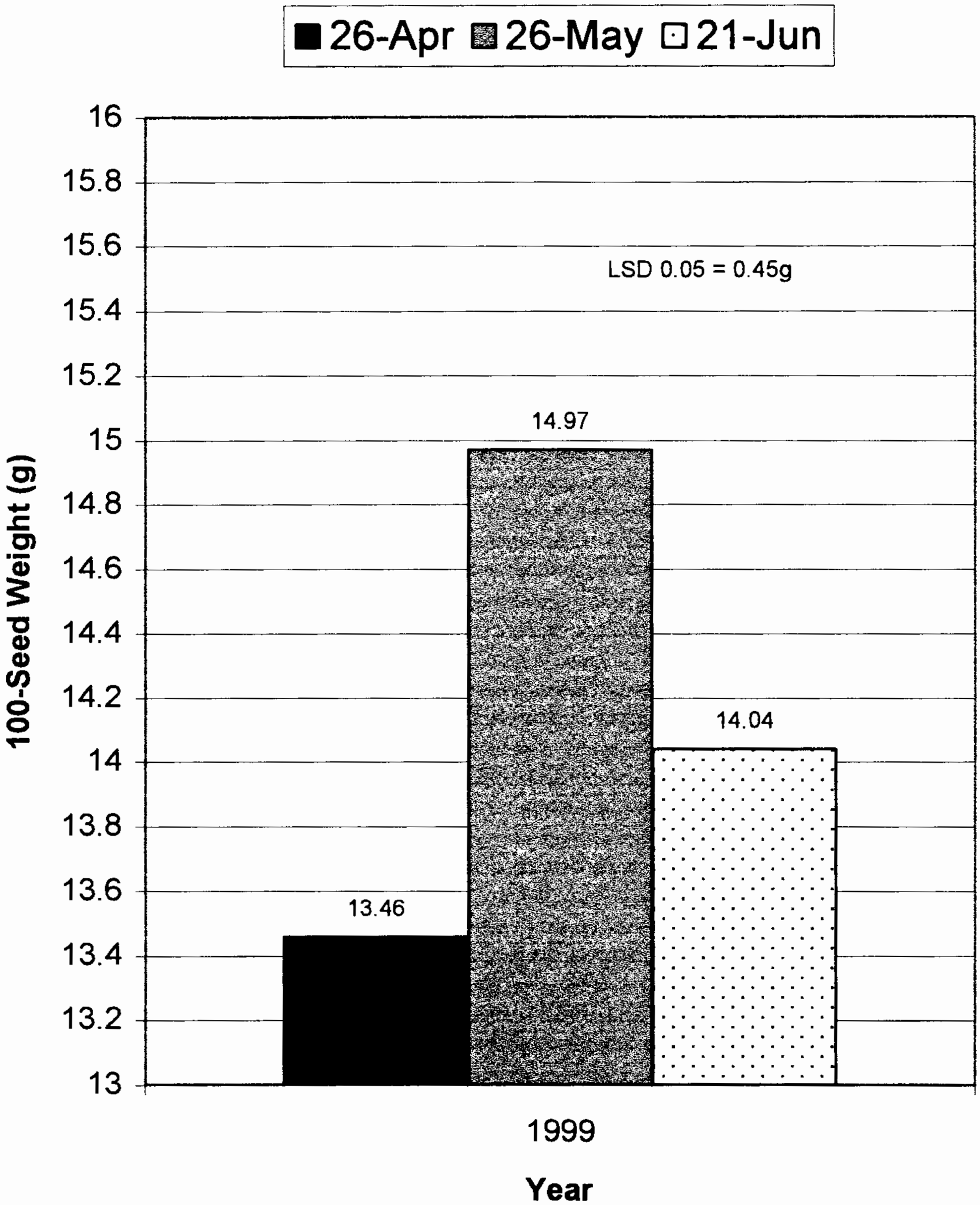
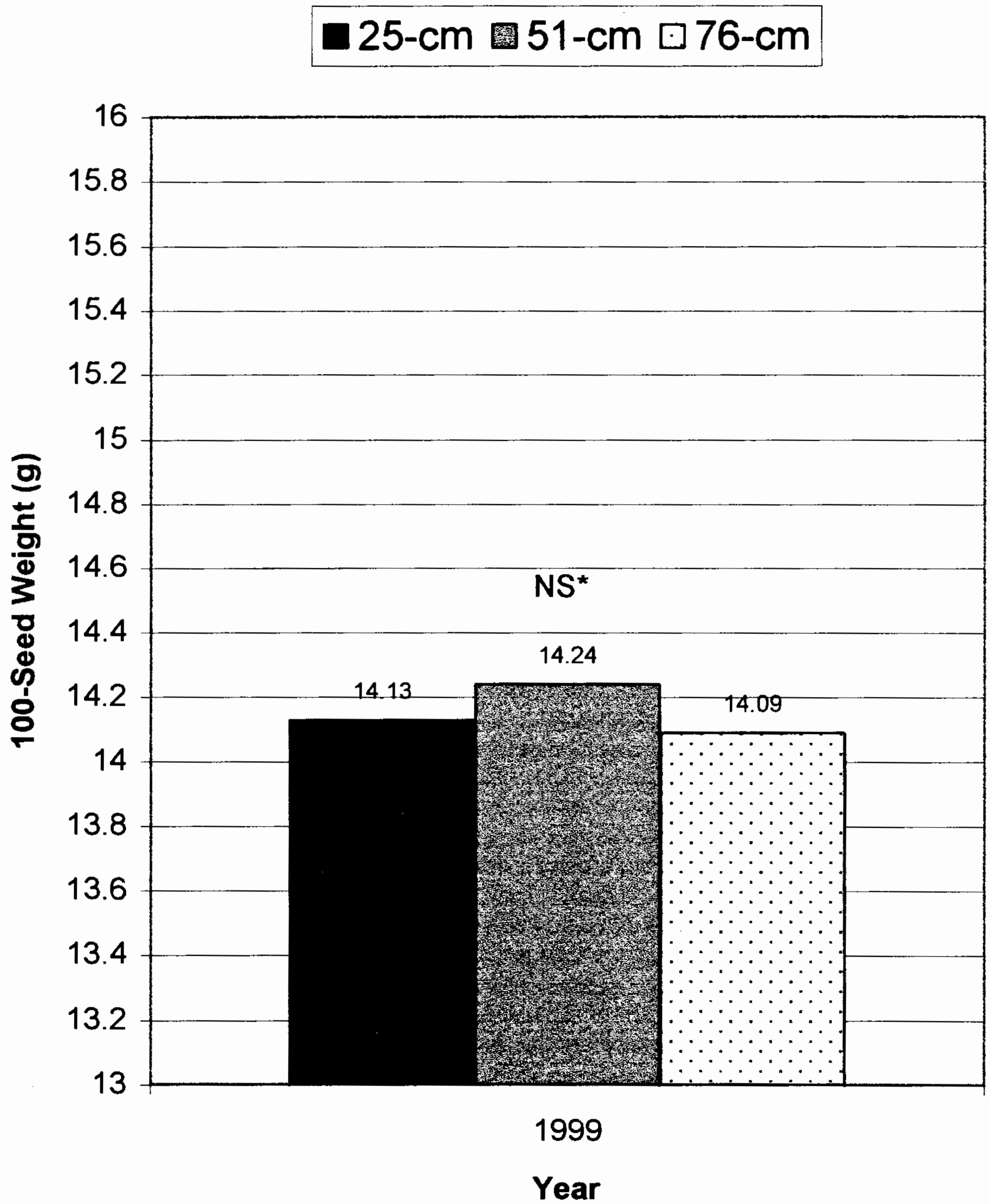


Figure 58. Planting date effect on 100-seed weight at the Nashua location (1999).



*NS denotes no significant statistical difference at the (P=0.05) level.

Figure 59. Row spacing effect on 100-seed weight at the Nashua location (1999).

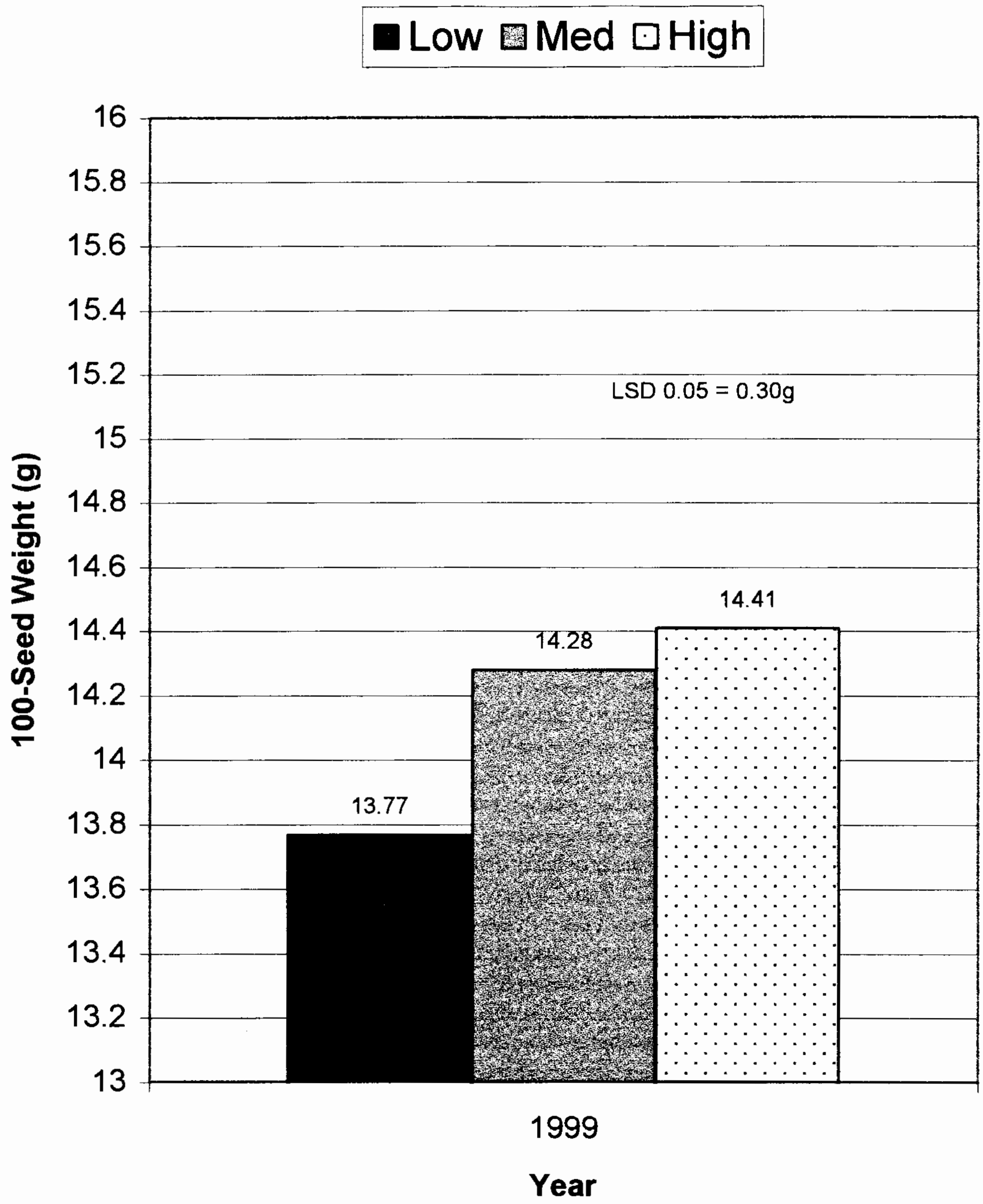


Figure 60. Seeding rate effect on 100-seed weight at the Nashua location (1999).

100-seed weight. The additional seeding rate increase to the high rate did not significantly increase 100-seed weight.

SUMMARY AND CONCLUSIONS

The growing conditions of the two seasons differed at the location near Ames, resulting in a direct year effect on soybean seed yield. The 1999 yields were reduced by approximately 17% due to late season stress that occurred during pod production and seed filling. The cool wet conditions, although experienced in both seasons, seemed to slow down soybean growth and development for a longer period of time in the 1999 season than in 1998. Plant populations and the third planting date varied significantly from the targeted plant populations and planting date in 1998. The soybeans, however, were able to take advantage of some favorable weather during July, August, and September, which provided the plant with a relatively stress-free environment. The pod production and seed filling time period was not under the stressful conditions in 1998 as it was in 1999.

Yield averages at the Northeast Research and Demonstration Farm near Nashua, in 1999 were much higher than those produced at the Ames location that same year. The growing conditions were much more favorable near Nashua than near Ames, leaving the crops with a fairly stress free environment. Other factors, such as cultivar, weed control, and tillage method, also may have influenced these yield differences. It is due to these differences that no direct comparisons were made between the two locations.

Planting date had a significant influence on soybean seed yield at each location. Planting date was the variable that most influenced soybean seed yield in both of the growing seasons. This result has been noted in past research as well (Beaver and Johnson, 1981). Data from each location suggest that there was a yield decline associated with each delay in planting date. This yield decline was significant in each season when planting was delayed until the third date. The first delay in planting did not produce a statistically significant yield loss in either season or location. The highest yields were produced on the earliest planting dates in both seasons, indicating that the cultivars being produced today can tolerate the cool, wet, early-season growing conditions. These data provide valuable information indicating that soybean planting dates earlier than previously recommended will not decrease soybean yield potential; therefore, producers should take advantage of early-season planting and reduce their risks of yield losses due to late planting.

The influence of row spacing on soybean seed yield differed between locations. The influence of row spacing at the location near Ames differed from many of the past studies. Many reports have indicated that as row spacing decreased, soybean yield increased (Taylor, 1980; Beuerlein, 1988; Grau et al., 1994). The data in this study indicated a significant reduction in soybean yield for the 19-cm row spacing as compared to the 38- and 76-cm spacings. There were no statistical yield differences observed between the 38- and 76-cm rows. This negative yield response most likely can be attributed to the poor emergence of the drilled (19-cm) treatments. The poor (wet) seedbed resulted in seed placement problems with the drill. Many seeds were exposed due to poor furrow closure. This resulted in a poor seed-to-soil contact, hindering germination and emergence. Furrow closure and seed placement was much more uniform for the treatments (38- and 76-cm) seeded with the planter than they were with the drill. In 1999, the seedbed was much more favorable and plant emergence was much higher and more consistent for all of the treatments than it was in 1998. The row spacing influence on seed yield in 1999 was not significant. There was a trend, however, indicating a slight yield increase as row spacing was reduced from both the 76- to the 38-cm spacing and from the 38- to the 19-cm spacing. Another Iowa study conducted by Wykle (1997) indicated a similar row spacing trend. The results from the northeast research location supported past research, indicating that soybean producers can see an advantage to narrow row widths. The 25- and 51-cm rows produced statistically similar yields that were significantly higher than the 76-cm treatment yields. Past results have indicated that this advantage intensifies as latitude increases due to the fewer growing degree-days. These data support the use of narrow row soybeans in the northern region of Iowa.

Seeding rate effects on yield were similar to the row spacing results. The seeding rate influence on soybean yield also differed at the two locations. In 1998, at the location near Ames, the low seeding rate produced yields significantly lower than the medium and high rates. Harvest populations were lower than the targeted rate in 1998 for almost all treatments. The early season growing conditions were most likely the primary cause for the lower plant populations. Several researchers have stated that cool and moist soil environments, which frequently occur in no-till systems, may be the primary reason for reduced soybean emergence (Unger and McCalla, 1980; Johnson and Lowery, 1985). In 1999, there was no significant yield response to changes in plant population. This supports past research that has indicated that soybeans can compensate well for reduced stands (Wilcox, 1974; Beuerlein, 1987). Plant population responses in the northeast study varied from many of the past studies. Yields increased as plant population increased in this experiment. The yield increase may have been due to the plant population influences on plant height, growth rate, and leaf area index accumulation rate that were discussed in the results.

The yield components measured in these experiments support the treatment effects on soybean yield. In both experiments, the yields were directly proportional with pod production, seed size, and seed weight. The results, however, indicate that the component that influenced yield the most was pod production. The soybean yield decrease at the location near Ames in 1999 can be supported by many of the yield components measured in this study. The seed size was decreased as well as the total number of pods produced in 1999. Many studies have concluded that pod number was the primary component in determining soybean seed yield (Enyi, 1973; Lueschen and Hicks, 1977). Others have stated that seed size was the primary compensatory factor (Wright et al., 1984; Moore, 1991). In this experiment, the reduced soybean seed yields at the location near Ames are attributed to both the lower seed size and lower pod production in 1999.

The following conclusions can be drawn from the data:

1. Planting soybeans as early as late April does not decrease the yield potential and helps to reduce the risks of yield loss due to late-planted soybeans. Producers should not wait to plant their soybeans, they should plant as soon as the soil conditions are favorable.
2. Planting soybeans with a row-crop planter in intermediate row spacings (38-cm) resulted in less plant stand variability than those planted with a grain drill. The intermediate rows produced higher (or statistically similar) yields than the 19-cm row spacing and statistically higher yields than the 76-cm row spacing. A positive yield response to narrow (25-cm) rows was observed in northeast Iowa, but not in central Iowa.

3. Plant population increases from low levels (247,000-296,400 seeds/ha) to medium levels (395,200-402,610 seeds/ha) significantly increased soybean seed yields. An additional increase in plant population did not significantly affect yields at the Ames location. At the northeast location, the additional increase to 555,750 seeds/ha significantly increased the soybean seed yield.
4. Desired harvest populations were not achieved for treatments in 1998. Stand variability due to an unfavorable seedbed was the primary reason. Stand variability was highest in the drilled treatments. These results indicate that seeding rate needs to be increased for no-till conditions in order to achieve desired harvest plant populations, especially when using a grain drill as opposed to a row-crop planter.

APPENDIX

Table 6. Mean squares from the analysis of variance of the combined data for the parameters measured (Ames 1998-1999).

Source of Variation	df	Seed Yield (kg/ha)	Plant Height (cm)	Pods Per Plant	Seeds Per/lb (seeds/kg)	Harvested seed size (g/100seeds)
Year	1	274,921.3**[1]	67.8*	1,504.2*	2,650,202.0**	113.1**
Date	2	360,487.8**	3447.5**	3,140.2**	215,570.6**	10.4**
Year x Date	2	9,339.4	0.8	864.5*	39,691.9	2.3**
Row Width (RW)	2	18,457.1**	4.8	817.5**	21,544.2*	2.9**
Year x RW	2	28,609.5**	16.3*	341.4*	44,028.9**	0.5
Date x RW	4	1,720.1	8.1	43.5	3,039.2	1.3**
Year x Date x RW	4	3,352.8**	0.3	179.6	2,010.1	0.8**
Population (POP)	2	6,423.4**	180.8**	2,335.2**	20,543.3*	0.6
Date x POP	4	2,035.9	0.5	49.8	15,226.8*	0.1
RW x POP	4	833.2	1.0	176.9	2,034.0	0.3
Date x RW x POP	8	255.3	0.8	165.2	3871.2	0.1
Error	162	1,075.0	4.1	103.5	5,398.9	0.2

[1]* and ** denote significance at the 0.05 and 0.01 levels of probability, respectively.

Table 7. Mean squares from the analysis of variance of the 1999 Nashua data for the parameters measured.

Source of variation	df	Seed Yield (kg/ha)	Plant Height (cm)	Pods Per Plant	Seeds Per/lb (seeds/kg)	Harvested seed size (g/100seeds)
Rep	3	4723.5	1.3	12.1	83,468.7	2.2
Date	2	249,711.6**	1361.7**	6259.1**	647,461.2**	20.9**
Rep x Date(error a)	6	1437.9**	3.0	26.2	6988.3	0.6
Row Width (RW)	2	4206.1**	15.2*	148.5	19,177.0	0.2
Date x RW	4	5059.4**	3.3	30.5	1567.0	0.4
Population (POP)	2	8365.2**	108.7**	5985.4**	93,611.7**	4.0**
Date x POP	4	1263.2**	3.6	31.9	44,900.1**	1.7**
Date x RW x POP	8	141.1	2.0	32.9	6486.9	0.3
RW x POP	4	443.5	3.0	9.8	2312.9	0.4
Residual (error b)	72	295.6	4.8	60.4	8935.3	0.4

[1]* and ** denote significance at the 0.05 and 0.01 levels of probability, respectively.

Table 8. Mean squares from the analysis of variance of the 1998 Ames data for the parameters measured.

Source of variation	df	Seed Yield (kg/ha)	Plant Height (cm)	Pods Per Plant	Seeds Per/lb (seeds/kg)	Harvested seed size (g/100seeds)
Rep	3	416.6	1.8	334.3	24,269.3	2.3
Date	2	242,938.9**	1714.0**	406.7	73,890.0**	6.9**
Rep x Date(error a)	6	3641.7	3.8	242.9	2965.6	0.2
Row Width (RW)	2	45,675.8**	19.1**	883.9**	35,038.5**	2.3**
Date x RW	4	221.7	3.0	174.3	3630.4	1.8**
Population (POP)	2	4851.1**	104.9**	1274.2**	6764.9*	0.1
Date x POP	4	2103.0*	0.3	111.3	3528.5	0.2
Date x RW x POP	8	1148.9	1.3	166.3	1606.6	0.1
RW x POP	4	1377.4	1.8	129.6	2878.9	0.1
Residual (error b)	72	880.2	3.6	166.0	1888.4	0.2

[1]* and ** denote significance at the 0.05 and 0.01 levels of probability, respectively.

Table 9. Mean squares from the analysis of variance of the 1999 Ames data for the parameters measured.

Source of variation	df	Seed Yield (kg/ha)	Plant Height (cm)	Pods Per Plant	Seeds Per/lb (seeds/kg)	Harvested seed size (g/100seeds)
Rep	3	1135.3	20.1	85.2	5213.7	0.6
Date	2	126,895.0**	1734.3**	3598.0**	81,372.5	5.9*
Rep x Date(error a)	6	4743.6	24.9	204.3	40,614.2	0.8
Row Width (RW)	2	1384.1	2.0	275.0**	30,534.6*	1.0**
Date x RW	4	4851.1**	5.3	48.7	1419.0	0.3
Population (POP)	2	1914.9	77.0**	1084.2**	14,692.3	0.6
Date x POP	4	3299.0**	0.8	13.2	16,464.3	0.1
Date x RW x POP	8	1377.4	0.5	56.6	6817.6	0.5**
RW x POP	4	1330.4	0.1	60.9	2352.5	0.7**
Residual (error b)	72	994.4	5.6	53.2	9108.2	0.2

[1]* and ** denote significance at the 0.05 and 0.01 levels of probability, respectively.

Table 10. Staging Dates for all treatments within a planting date at the Ames location, (1998 and 1999) and at the Nashua location (1999).

Treatment

1998 Ames Planting Date	VC[1]	V5	R1	R8
5-May	18-May	10-June	22-June	9-September
19-May	29-May	17-June	30-June	23-September
24-June	30-June	15-July	27-July	11-October
1999 Ames Planting Date	**VC**	**V5**	**R1**	**R8**
3-May	19-May	18-June	1-July	19-Septmeber
25-May	2-June	27-June	13-July	26-September
17-June	23-June	17-July	31-July	4-October
1999 Nashua Planting Date	**VC**	**V5**	**R1**	**R8**
26-April	11-May	31-May	20-June	14-September
26-May	3-June	26-June	9-July	25-September
21-June	27-June	14-July	25-Jul	7-October

[1]Plots were considered a given stage when 50% of the plants had achieved that stage.

Table 11. Means for percent protein, percent oil, and percent fiber of harvested seed for all treatments at the Ames location (1998 and 1999).

Treatment	1998			1999		
	% Protein	% Oil	% Fiber	% Protein	% Oil	% Fiber
Date 1						
19-cm Low[1]	34.3	20.0	5.3	35.5	18.5	4.9
19-cm Med	35.2	19.5	5.4	35.7	18.5	4.9
19-cm High	34.6	19.9	5.4	35.9	18.7	4.8
38-cm Low	34.4	19.8	5.4	35.8	18.5	4.8
38-cm Med	35.0	19.7	5.4	36.2	18.7	4.8
38-cm High	34.3	19.9	5.4	35.7	18.5	4.8
76-cm Low	34.1	19.9	5.4	36.1	18.4	4.8
76-cm Med	35.3	19.7	5.4	35.6	18.7	4.8
76-cm High	35.7	19.5	5.3	35.9	18.7	4.8
Date 2						
19-cm Low	35.8	18.9	5.3	36.5	18.0	4.8
19-cm Med	35.0	19.3	5.2	37.0	17.8	4.8
19-cm High	35.7	19.1	5.3	36.7	17.6	4.8
38-cm Low	35.6	19.0	5.3	36.3	18.3	4.8
38-cm Med	35.5	18.9	5.3	36.6	17.8	4.9
38-cm High	36.1	19.0	5.4	36.7	17.8	4.9
76-cm Low	36.0	19.3	5.5	36.1	17.9	4.9
76-cm Med	35.7	19.1	5.3	36.5	18.0	4.9
76-cm High	36.3	19.0	5.4	37.2	17.9	4.8
Date 3						
19-cm Low	36.0	18.4	5.5	36.7	17.1	5.0
19-cm Med	35.6	18.5	5.4	36.9	17.1	4.9
19-cm High	35.1	18.5	5.3	37.0	17.1	4.9
38-cm Low	35.9	18.5	5.5	37.1	17.0	5.1
38-cm Med	35.3	18.5	5.2	36.3	17.1	5.1
38-cm High	35.8	18.2	5.4	36.8	16.9	5.0
76-cm Low	35.2	18.6	5.3	36.4	17.5	5.0
76-cm Med	35.9	18.4	5.3	36.8	17.1	5.0
76-cm High	35.7	18.3	5.4	36.9	17.3	4.9

[1]Seeding rates were 296,400 plants/ha (Low), 395,200 plants/ha (Med), and 494,000 plants/ha (High). Actual harvest stands shown in table #.

Table 12. Means for percent protein, percent oil, and percent fiber of harvested seed for all treatments at the Nashua location (1999).

Treatment	1999		
	% Protein	% Oil	% Fiber
Date 1			
25-cm Low[1]	35.9	17.7	5.1
25-cm Med	36.0	17.7	5.1
25-cm High	36.2	17.5	5.2
51-cm Low	36.5	17.3	5.2
51-cm Med	35.3	17.5	5.2
51-cm High	36.0	17.9	5.0
76-cm Low	35.2	18.1	5.0
76-cm Med	35.8	18.1	5.0
76-cm High	36.1	17.8	5.0
Date 2			
25-cm Low	36.3	17.5	5.1
25-cm Med	37.1	17.4	5.0
25-cm High	37.3	17.2	5.1
51-cm Low	36.8	17.5	5.1
51-cm Med	37.1	17.5	5.0
51-cm High	37.3	17.4	5.0
76-cm Low	36.8	17.6	5.0
76-cm Med	37.1	17.6	5.1
76-cm High	37.2	17.2	5.1
Date 3			
25-cm Low	37.1	16.0	5.3
25-cm Med	37.7	16.0	5.2
25-cm High	38.4	16.1	5.1
51-cm Low	36.8	17.0	5.1
51-cm Med	37.7	16.5	5.1
51-cm High	38.3	16.0	5.1
76-cm Low	37.0	16.3	5.3
76-cm Med	37.6	16.8	5.1
76-cm High	37.7	16.3	5.2

[1]Seeding rates were 247,000 plants/ha (Low), 402,610 plants/ha (Med), and 555,750 plants/ha (High). Actual harvest stands shown in table #.

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